Cognitive Load and the Perception of Time

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts at George Mason University

by

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DEDICATION

This is dedicated to my parents, Stephen and Julie, and my sister, Courtney.

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Thank you to my advisor, Dr. Martin Wiener, for his mentorship and support throughout my undergraduate and graduate studies. I would also like to thank the members of my committee, Dr. Craig McDonald and Dr. James Thompson, for their help on my thesis. Finally, I would like to thank the members of the S.T.A.R. Lab for their encouragement.

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ABSTRACT

COGNITIVE LOAD AND THE PERCEPTION OF TIME

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This thesis examined the role of instruction protocol and order of visual stimuli as methods of cognitive loading on the perception of time. A duration discrimination task was conducted in which the same participant pool was presented with two sets of instructions, as well as with visual stimuli presented in a standard-comparison or comparison-standard order. Previous research indicated that tasks with high cognitive load led to increased errors in discriminating intervals of time due to demands on the allocation of attentional resources and working memory. The results of the present study revealed that the combination of instruction protocol and order of visual stimuli had significant effects on the accuracy, but not the precision, of time perception in the duration discrimination task. It is thought that the use of instruction protocol may have mitigated the effects on precision, but further research is necessary to verify. Overall, the results of this study provide implications for real-world learning and how cognitive load interacts with human time perception and performance on tasks.

INTRODUCTION

The relationship between cognitive load and time perception is dynamic and becoming increasingly relevant in the present moment. As humans become ever more engrossed with technology and the social norm of multitasking, attention and memory can become overloaded. How does having more to attend to influence the perception of time? The idioms *Time flies when you are having fun* or *A watched pot never boils* play on the role of attention in temporal processing. However, the cognitive load of a task may additionally play a role in temporal processing.

Referring to the fundamentals of time perception, Ivry & Schlerf (2008) defined two models of timing: dedicated and intrinsic. The dedicated model of time perception states that the duration judgment of a stimulus relies on dedicated neural structures, such as those found in the frontal cortex, hippocampus, basal ganglia, and cerebellum (Harrington, Haaland, & Knight, 1998; Meck, 2005). The intrinsic model of time perception states that temporal information is represented by ubiquitous, non-dedicated neural structures. The scalar expectancy theory (SET) is a prominent example of a dedicated model of time perception. SET generally illustrates the perception of time as involving an internal clock that records the passage of time from an arbitrary signal event (Gibbon, 1991). Important times are then recorded in reference memory for future recall. An information-processing version of SET was previously developed to account for attention and decision-making (Gibbon, Church, & Meck, 1984). This version of SET includes three processes: the clock process, memory process, and decision process. Once more, the perception of time involves an internal clock, or pacemaker mechanism, which generates pulses in response to an arbitrary signal event. There is then a switch that can open and close to control the accumulation of pulses to a memory storage mechanism. The number of accumulated pulses is recorded in working memory and, if reinforced, will move to a more permanent reference memory for later comparison. The decision process occurs in a comparator, which judges the current value in working memory to a stored value in reference memory, leading to the subjective perception of time for the respective interval. As such, the more pulses that are accumulated, the longer the perceived duration of time.

It is notable to emphasize that in the information-processing version of SET, the switch is under the control of attentional mechanisms (Meck, 1984). This connects back to the idea of cognitive load, which is described as the amount of information-processing, attentional, or working memory demands during a specified time or demanded by a primary task (Block, Hancock, & Zakay, 2010). Cognitive load is near-synonymous with other terms used in the literature, such as *load*, *mental workload*, *cognitive workload*, and *workload*. Indeed, as the cognitive load of a primary task increases, the performance on a secondary task will decrease. For example, imagine driving a car on the highway during rush hour while also trying to use a cell phone. If the primary task is driving the car, the performance of using a cell phone will likely decrease. If the primary task is using a cell phone, the performance of driving the car will likely decrease. Cognitive load inherently plays a part in everyday life and can have profound real-world implications. Yet, how does cognitive load influence the perception of time? To make this determination, it is noteworthy to consider the attentional mechanisms of time perception, temporal memory, as well as the various paradigms of cognitive load.

The attentional demands involved in the perception of time bring about two paradigms: the prospective paradigm and the retrospective paradigm. The prospective paradigm is when a person is made aware that a duration judgment must be made, while the retrospective paradigm is when a person is not made aware that a duration judgment must be made (Zakay & Block, 2004). As such, the prospective paradigm requires participants to recall the experienced duration, which relies on attention to temporal information contending with attention to nontemporal information. The retrospective paradigm requires participants to recall the experienced duration dependent on incidental memory for temporal information. It is further suggested that duration judgments made in the prospective paradigm, but not the retrospective paradigm, can be used as a measure of the amount of cognitive load required for the performance of a nontemporal task, such as a Stroop task or card-sorting task (Zakay, Block, & Tsal, 1999). In this study by Zakay and colleagues, participants were required to complete a nontemporal task while also completing either a duration-production or a duration-estimation task. Likewise, participants were required to rate the level of workload (i.e., cognitive load) associated with the tasks. The results indicated that produced durations on the timing tasks were highly correlated with workload ratings and performance indices on the non-temporal tasks. Going further, research has shown that when the prospective timing task is defined as a primary task, the time estimates increase (Zakay & Block, 1996). On the contrary, when the prospective timing task is defined as a secondary task, the time estimates decrease. The authors suggested that this effect occurs because of the allocation of attentional resources.

Along a similar line of research, Brown (1997) connected the concepts of attentional resources in timing to cognitive load. Three experiments that required participants to complete concurrent temporal and nontemporal tasks found that concurrent nontemporal tasks prompted temporal productions to become longer or more variable than the temporal-only tasks. This study also generated a relevant conclusion that timing is sensitive to cognitive demands, such that temporal productions were disrupted by all three concurrent nontemporal tasks, even when these tasks were associated with relatively light processing loads.

A later study by Brown & Boltz (2002) further investigated the role of attention in timing and its effects on cognitive load and event structure. Two experiments were conducted, with the first requiring participants to reproduce durations of melodies with either a coherent or incoherent structure under timing only or timing plus target detection workload conditions. The results showed that reproductions were shorter and more inaccurate under the timing plus target detection conditions. In the second experiment, participants reproduced durations of auditory prose passages that represented three levels of mental workload and three levels of event structure. Again, the results indicated inaccurate reproductions as a function of increased workload. Taken together, this study supports that timing is affected by cognitive load, such that duration judgments are made with more errors under tasks with higher loads compared to those with lower loads. The authors suggested that this is a consequence of greater amounts of attentional resources being diverted away from the timing task, which is a similar conclusion found across the literature.

Baldauf, Burgard, & Wittmann (2009) brought the role of cognitive load in time perception to a realistic occurrence by requiring participants to perform a time-production task while operating a driving simulator. This study draws upon how cognitive load is experienced throughout daily tasks, such as driving a car. The results found that the length of produced intervals increased in more complex driving situations, along with increases in electrodermal activity and subjective ratings of mental workload. The authors determined that time perception is a valid indicator of cognitive involvement in simulated driving and that a time-production task is sensitive to changes in cognitive load level.

It is consistently found that as the complexity of a task increases, and thus the cognitive load is thereby increased, time intervals are judged with less accuracy as a function of attention. However, several past studies found that higher cognitive load leads to an underestimation of time, and other studies suggest that it leads to an overestimation of time (Thomas & Weaver, 1975; Zakay, 1989). Further research into the role of cognitive load in time perception and the subsequent attentional resources allocated is necessary to structure a more robust theory.

It is also of note to discern response demands and processing changes in cognitive load as an effect on the perception of time. The meta-analysis by Block and colleagues (2010) described these load types concerning duration judgments. Response demands are a cognitive load manipulation that requires participants to actively respond to presented information (high load) or passively view or hear information (low load) while completing a timing task. When making prospective duration judgments, the authors found a smaller mean effect size ratio if the response demands required active processing instead of passive processing. This implies that duration judgments decreased if a person had to respond to presented stimuli compared to passively perceiving the stimuli. Regarding processing changes, this type of cognitive load manipulation requires participants to change the type of information-processing performed while completing a timing task. For example, some experiments required participants to alternate between structural and semantic levels of processing (high load) compared to structural-only or semantic-only processing during the duration (low load). The authors did not find a significant mean effect of processing changes but noted that previous studies found load to be greater when a participant is required to change the type of information-processing performance compared to the processing type being constant. Therefore, prospective duration judgments were affected as a function of task switching and attentional demands (Gopher, Armony, & Greenshpan, 2000; Block & Reed, 1978; Martinez, 1991, as cited in Block et al., 2010). Again, further research investigating the effects of cognitive load on duration judgments is necessary to refine theories on human time perception.

Another line of research to consider regarding cognitive load in time perception is the role of memory. Timing can be manipulated by attentional and memory processes (Block & Gruber, 2014). As described previously, cognitive load demands the allocation of attentional resources, thus implicating memory in its function. Working memory, which is involved in both cognitive load and duration judgments, is defined by Baddeley (1992) as a brain system that temporarily stores and manipulates information necessary for complex cognitive tasks. It requires the simultaneous storage and processing of information as a function of the short-term memory system. The author described an earlier study that required participants to remember digits while performing a cognitive task, finding that as concurrent digit load increased, performance on the cognitive task declined. This effect was seen across reasoning, comprehension, and learning tasks and is attributed to the interference of cognitive load on the working memory system.

Regarding time perception and working memory, three experiments conducted by Pan & Luo (2012) indicated that holding a stimulus in working memory can lead to a longer subjective duration for the stimulus. In Experiment 1, participants were exposed to a visual memory cue that was to be retained in working memory. During this retention period, participants were then shown two colored circles in succession (with one circle matching the color of the visual memory cue), followed by determining which circle appeared for a longer duration. Finally, participants were tested on the visual memory cue. In Experiment 2, there was a similar method, however, participants were asked to attend to the visual memory cue, but there was no memory test at the end of the trial. Additionally, participants only carried out the duration judgment task when the cue was a colored square, which occurred in 80% of trials. Experiment 3 utilized verbal memory cues instead of visual. As mentioned previously, the results of this study established that working memory modulates time perception. While holding a stimulus in working memory led to a longer subjective duration for the stimulus, mere exposure to the memory cue without working memory processing led to a shorter subjective duration for the stimulus (when the color of the stimuli matched the perceptual cue). This effect was seen across visual and verbal stimuli and is thought to occur due to top-down modulation from the nontemporal contents of working memory. Along a similar line of research, Üstün, Kale, & Çiçek (2017) conducted an fMRI study to identify the neural networks involved in time perception and working memory. Participants were shown a moving black rectangle containing a random number of dots at a variable speed. Likewise, there were three experimental conditions: the time perception condition, memory condition, and time-memory condition. In the time perception condition, participants attended to the speed of the rectangle. In the memory condition, participants attended to the number of dots on the rectangle. In the time-memory condition, participants attended to both speed of and the number of dots on the rectangle. The results of this study revealed a significant interaction between the time perception and working memory conditions, as well as the lowest performance to be in the time-memory condition. As for the neuroimaging results, both time perception and working memory were related to a strong peristriate cortical activity. The interaction of the two, because of the time-memory condition, showed activity in the intraparietal sulcus (IPS) and posterior cingulate cortex (PCC).

Being that working memory appears to be involved in cognitive load and time perception, it brings about the question of how these processes may interact. Specifically, these processes suggest the role of temporal memory, which is memory for temporal information, such as event duration, occurrence, order, etc. (Harrison & Horne, 2000; Meck, 1996). Grondin (2005) conducted a study to identify memory as a major source of variance in temporal processing. This was done by manipulating cognitive load in a timing task requiring participants to categorize a stimulus as appearing for a short or long duration. The author noted that previous research supports varying cognitive load as a method of testing memory. As such, two modalities (auditory and visual) and two base durations (250 ms and 750 ms) were used as loading conditions. Each session of the experiment included a particular combination of modality and base duration. The lowest loading condition of the task included one modality and one base duration (i.e., only auditory stimuli with a base duration of 250 ms in a single session), while the highest loading condition of the task included two modalities and two base durations (i.e., both auditory and visual stimuli with a base duration of 250 ms or 750 ms). The results of this study showed that the use of two base durations in a session increased the number of discrimination errors compared to the use of a single-base duration. However, the number of discrimination errors did not rise when the number of modalities in a session is increased. The author attributed the effect of base duration on duration discrimination as relating to the loading effect on temporal memory. For instance, increasing the number of base durations also increases the number of representations of interval distribution in memory. The temporal processing system is overloaded and stressed by the retention of more than one temporal representation, leading to errors in overall time perception.

The study by Grondin (2005) established a relationship between cognitive load and the perception of time, which can be further elaborated by Jones & Wearden (2004). Across three experiments, the authors sought to investigate memory (i.e., cognitive) loading in temporal reference memory. Experiments 1 and 2 functioned similarly, as participants were presented with two different standard durations and instructed to encode either one or both. When encoding one standard duration, participants were required to determine if the comparison stimulus was or was not the standard duration. As for encoding two standard durations, the same procedure was followed, but only one of the standard durations was tested. In Experiment 3, participants were presented with two standard durations to encode, and both were tested. The results of Experiment 1 and Experiment 2 proved to be non-significant. However, the results of Experiment 3 demonstrated an effect of increasing memory load on temporal generalization performance, which suggested that encoding two temporal standards in reference memory and having to use them both for decision-making increased the variability of representations in reference memory. Thus, once more, the literature supports that cognitive load and memory influence time perception.

While previous research has often manipulated cognitive load through task switching or stimuli encoding, La Dantec et al. (2006) fortuitously influenced cognitive load with instructions. In this ERP study, the authors set out to explore the functional dynamics between the prefrontal cortex (PFC) and parietal association cortex (PAC) and their participation in the functional loops underlying temporal processing. Participants completed a duration discrimination task, which acts on selective attention and short-term memory functions. The task requires participants to compare the duration of two temporal intervals presented in succession. In this study, the two temporal intervals were a white spot presented on a computer screen. The stimuli could be presented in the order of short-long (250-500 ms) or long-short (500-250 ms). As previously mentioned, instructions were relevant. Half of the participants discriminated whether the first stimulus duration was shorter or longer than the second stimulus duration, which classified Instruction 1. The other half of the participants discriminated whether the second stimulus duration was shorter or longer than the first stimulus duration, which classified Instruction 2. The behavioral performance results indicated a triple interaction between stimulus duration, presentation order, and instruction protocol. Participants performed better for the long-short (500-250 ms) order of presentation. Furthermore, participants performed better when required to compare the first stimulus duration to the second stimulus duration compared to the reverse. The authors suggested that this is due to Instruction 1 fostering the most natural strategy and requiring less temporal information to be held in working memory. The ERP results indicated that activity at the PFC and PAC are linked to selective attention and working memory processes underlying duration discrimination. As participants only experienced Instruction 1 or Instruction 2, the authors noted that future studies should obtain results from the same participants using both instruction protocols, which connects to the present study.

The current literature suggests a role of cognitive load in time perception, but there are discrepancies in the specific effects cognitive load has on judging durations. Research has also yet to comprise instruction protocol as a method of manipulating cognitive load across the same participants. Therefore, the present study asked the following question: How does instruction protocol and order of visual stimuli as a method of cognitive loading affect the perception of time?

To answer this question, a duration discrimination task was conducted in which the same participant pool will be presented with two sets of instructions. Likewise, the visual stimuli were presented in a standard-comparison or comparison-standard order. Instruction 1 required the duration of the *first* visual stimulus to be compared to the duration of the *second*. Instruction 2 required the duration of the *second* visual stimulus to be compared to the duration of the *first*. The first visual stimulus would appear for a standard S, constant duration (500 ms), or comparison C, varying duration (300-900 ms), while the second visual stimulus would appear for the opposite. It was hypothesized that the instruction protocol and order of visual stimuli that required participants to hold temporal information in working memory and demand increased attention would result in less accurate and less precise judgments of durations due to the high cognitive load produced. Trials with Instruction 1 and C-S order, and with Instruction 2 and S-C order would be associated with better performance on the duration discrimination task. Alternatively, trials with Instruction 1 and S-C order, and with Instruction 2 and C-S order would be associated with worse performance on the duration discrimination task. It was predicted that the effects on time perception would be a function of attentional demands and memory that are fundamental to varying levels of cognitive load.

METHOD

Participants

Fifty students from George Mason University participated in the experiment. Eligible participants were 18 to 35 years old with normal or corrected-to-normal vision and no history of neurological or psychological illness. Participants were recruited through the George Mason University Sona Experiment Management System, and they took part in the experiment to satisfy psychology course credit requirements or as volunteers. All participants were rewarded with one Sona Systems.

Materials

The experiment was conducted online. As such, the materials required for the experiment were personal computers equipped with a monitor, standard keyboard, and internet access. Participants needed an active George Mason University Sona Systems account to access and complete the experiment. The experiment was built and coded using PsychoPy [v2022.1.2] and administrated through Pavlovia, which is a web application for running online experiments. MATLAB [R2022a] and JASP [0.16.1.0] were used to run statistical analyses of data. At the start of the experiment, participants were required to complete an informed consent form and demographic questionnaire, which was embedded within the experiment.

Task. A duration discrimination task was utilized for the experiment. As described previously, this task requires participants to compare the duration of two temporal intervals presented in succession. Throughout the task, the background color of the screen was gray, with black Arial font type and 0.03 letter height. The experiment was divided into four conditions that occurred in random order. The visual stimulus employed in the experiment was a white circle that appeared in the center of the screen. Conditions 1 and 2 were preceded with one set of instructions, while Conditions 3 and 4 were preceded with a different set of instructions. Reaction time was not considered in the task, nor was feedback given to participants. The durations in which the visual stimuli appeared were in milliseconds, with the intention that participants could not complete the task by counting and forcing them to rely on their subjective perception of time.

Condition 1. The task began with the first set of instructions, directing participants to determine if the *first* white circle appeared for a shorter or longer length of time than the *second* white circle. Participants were instructed to use the ‘S’ key on the keyboard to indicate shorter and the ‘L’ key to indicate longer. Then, there was the presentation of a black fixation cross in the center of the screen for 500 ms. Next, the first white circle appeared for 500 ms. There was then a brief gap of 1000 ms, followed by the second white circle that appeared for one of seven durations (300 ms, 400 ms, 500 ms, 600 ms, 700 ms, 800 ms, or 900 ms). The duration in which the second visual stimulus appeared was randomized. Finally, text appeared in the center of the screen, and participants were instructed to press the ‘S’ or ‘L’ key on the keyboard to indicate whether the first white circle appeared for a shorter or longer length of time than the second white circle, respectively (see Figure 1). Note that Condition 1 was defined by Instruction 1, a standard S first white circle, and a comparison C second white circle. Condition 1 will be referred to as [S]-C, with the brackets indicating which visual stimulus participants were instructed to attend to.

Condition 2. The task for the second condition followed the same instructions and similar methodology as Condition 1. However, in this condition, the first white circle appeared for one of seven randomized durations (300-900 ms), and the second white circle appeared for 500 ms (see Figure 2). Note that Condition 2 was defined by Instruction 1, a comparison C first white circle, and a standard S second white circle. Condition 2 will be referred to as [C]-S.

Condition 3. The task for the third condition followed a similar methodology as Condition 1. However, in this condition, participants were presented with the second set of instructions, directing them to determine if the *second* white circle appeared for a shorter or longer length of time than the *first* white circle (see Figure 1). Note that Condition 3 was defined by Instruction 2, a standard S first white circle, and a comparison C second white circle. Condition 3 will be referred to as S-[C].

Condition 4. The task for the fourth condition followed the same instructions and similar methodology as Condition 3. However, in this condition, the first white circle appeared for one of seven randomized durations (300-900 ms), and the second white circle appeared for 500 ms (see Figure 2). Note that Condition 4 was defined by Instruction 2, a comparison C first white circle, and a standard S second white circle. Condition 4 will be referred to as C-[S].

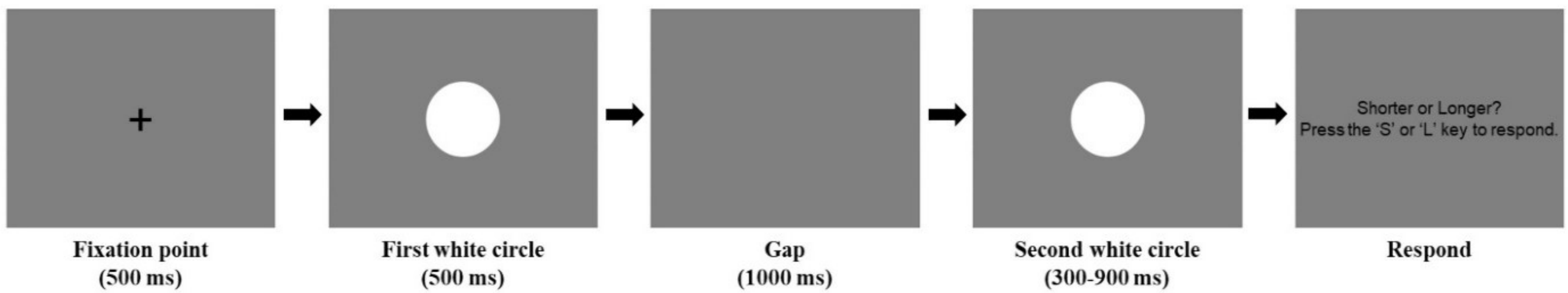

Figure 1 Duration Discrimination Task for S-C Conditions

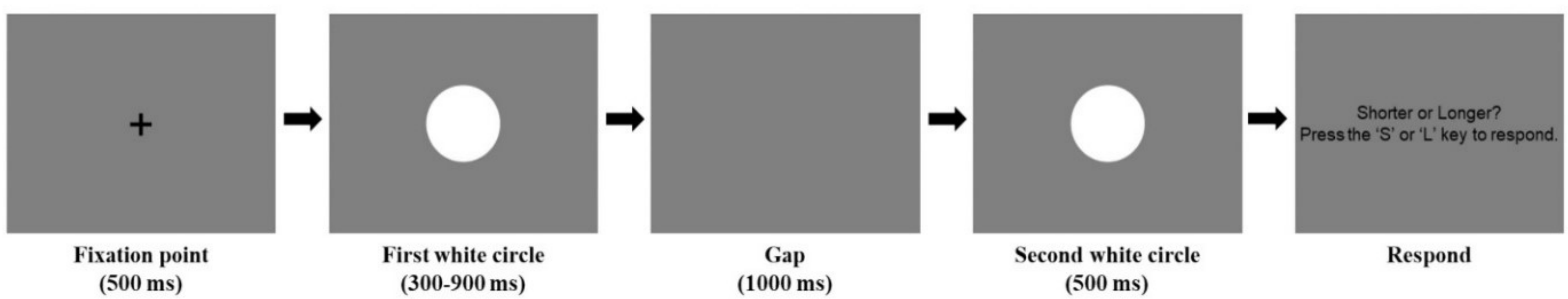

Figure 2 Duration Discrimination Task for C-S Conditions

Procedure

Participants logged in to Sona Systems using an internet web browser, signed-up for the study, and used the provided link to access the experiment. Clicking the link opened the experiment on Pavlovia. Participants read and signed the informed consent form and completed the demographic questionnaire, both of which were embedded within the experiment. Next, participants were presented with written text welcoming them to the experiment and clicked through a series of instructions directing them on how to complete the experiment. Primarily, participants were informed to determine if a white circle appeared for a shorter or longer length of time than another white circle. The white circles were presented on-screen and in succession for different lengths of time, separated by a brief gap. Additionally, participants were informed that there will be two different sets of instructions in the experiment. The specific instructions were presented at the beginning of each block. To respond if the white circle appeared for a shorter or longer length of time, participants were told to press the 'S' key for shorter and the 'L' key for longer.

After reading through the instructions, participants began a practice section. There were two blocks of the practice section corresponding to the two sets of instructions. The first practice section block instructed participants to determine if the *first* white circle appeared for a shorter or longer length of time than the *second* white circle. The methodology for Condition 1 (i.e., [S]-C) was utilized for the practice section and consisted of one trial per the randomized seven durations, with seven trials in total. Participants then completed the second practice section block in which they were instructed to determine if the *second* white circle appeared for a shorter or longer length of time than the *first* white circle. The methodology for Condition 3 (i.e., S-[C]), was utilized for the practice section and consisted of one trial per the randomized seven durations, with seven trials in total. Following the practice section, participants were informed that the experiment section would now begin and to press the 'spacebar' key when they were ready to move on. The first or second set of instructions would appear, and again, participants were told to press the 'spacebar' key when they were ready to begin. If the first set of instructions were presented, participants completed the task following [S]-C or [C]-S conditions. If the second set of instructions were presented, participants completed the task following S-[C] or C-[S] conditions. Participants were not informed whether the first or second white circle is the standard S or comparison C. After completing a block, instructions for the next block appeared.

The instructions were designed so that participants could take self-paced breaks between blocks to prevent fatigue. Each block followed one of the four conditions, consisting of seven trials per the randomized seven durations (i.e., each duration will randomly occur seven times). Each condition was repeated four times, in random order. Thus, there were 49 trials in a single block and 784 trials in total, across the four conditions. The experiment took approximately 45 to 60 minutes. A written message appeared to end the experiment.

Data Analysis

MATLAB was used to calculate the average proportion of 'long' responses for each of the four conditions. The point of subjective equality (PSE) and coefficient of variation (CV) were also assessed. The PSE is defined as the duration at which a variable stimulus is judged by an observer to be equal to a standard stimulus and is a measure of bias or accuracy (Vidotto, Anselmi, & Robusto, 2019). The CV is the slope of the psychometric function divided by the PSE and is a measure of precision (Bizo et al., 2005; Nichelli, 1996). From the PSE and CV data, an automated MATLAB function was used to remove potential outlier participants. MATLAB was also used to fit the data with psychometric curves. The psychometric function was plotted, with duration on the x-axis and the proportion of 'long' responses on the y-axis. Next, JASP was used to calculate the average PSEs and CVs for each condition. Lastly, JASP was also used to conduct two separate repeated-measures ANOVAs and two separate paired samples t-tests to identify significant differences between the conditions based on the instruction protocol and order of visual stimuli. These tests were conducted accordingly for the PSE and CV values.

RESULTS

The average proportion of 'long' responses were calculated and fit with psychometric curves. Figure 3 displays the psychometric function per the four conditions. The visual appearance of the psychometric curves indicates a flatter S-shaped curve for all conditions, but more so for [S]-C, [C]-S, and C-[S] than S-[C]. To look further at the results, Table 1 displays the descriptive statistics for the PSE data. [S]-C had an average PSE of 0.454 (*SD* = 0.209). [C]-S had an average PSE of 0.590 (*SD* = 0.233). S-[C] had an average PSE of 0.500 (*SD* = 0.138). C-[S] had an average PSE of 0.416 (*SD* = 0.224). Table 2 displays the descriptive statistics for the CV data. [S]-C had an average CV of 0.282 (*SD* = 0.148). [C]-S had an average CV of 0.280 (*SD* = 0.175). S-[C] had an average CV of 0.284 (*SD* = 0.188). C-[S] had an average CV of 0.343 (*SD* = 0.259).

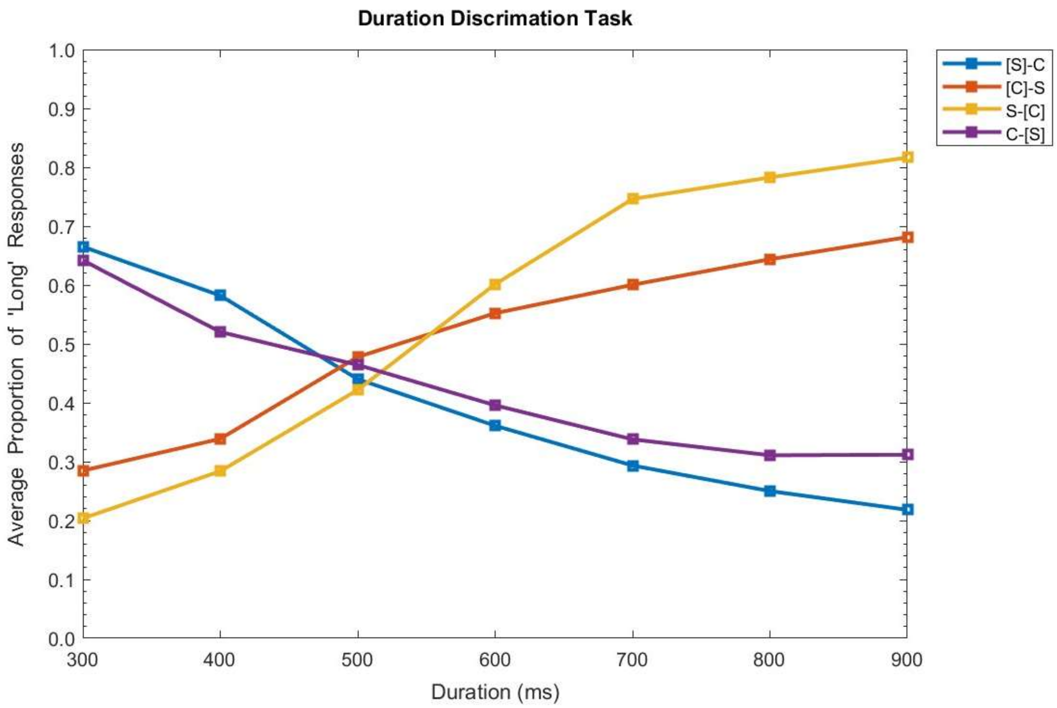

Figure 3 Psychometric Curves for each Condition

Table 1 Descriptive Statistics of PSE Data

Condition	N	Mean	SD	SE
[S]-C	42	0.454	0.209	0.032
[C]-S	42	0.590	0.233	0.036
S-[C]	42	0.500	0.138	0.021
C-[S]	42	0.416	0.224	0.035

Table 2 Descriptives Statistics of CV Data

Condition	N	Mean	SD	SE
[S]-C	43	0.282	0.148	0.023
[C]-S	43	0.280	0.175	0.027
S-[C]	43	0.284	0.188	0.029
C-[S]	43	0.343	0.259	0.040

Two separate repeated-measure ANOVAs were then conducted to compare the conditions based on instruction protocol (2 levels) and order of visual stimuli (2 levels). For the PSE data, which is displayed in Table 3, there was a significant main effect of instruction protocol ($F(1, 41) = 6.517$, $p = 0.015$, $\eta^2 = 0.027$), but no significant main effect of order of visual stimuli ($F(1, 41) = 0.521$, $p = 0.475$, $\eta^2 = 0.004$). However, the results indicated a significant interaction between instruction protocol and order of visual stimuli ($F(1, 41) = 8.885$, $p = 0.005$, $\eta^2 = 0.084$). As for the CV data, which is displayed in Table 4, there was no significant main effect for instruction protocol ($F(1, 42) = 1.200$, $p = 0.280$, $\eta^2 = 0.011$) or order of visual stimuli ($F(1, 42) = 1.009$, $p = 0.321$, $\eta^2 = 0.008$). Likewise, there was not a significant interaction between instruction protocol and order of visual stimuli ($F(1, 42) = 1.757$, $p = 0.192$, $\eta^2 = 0.010$).

Table 3 Repeated-Measures ANOVA for PSE Data

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Instruction Protocol	0.183	1	0.183	6.517	0.015	0.027
Residuals	1.151	41	0.028			
Order of Visual Stimuli	0.028	1	0.028	0.521	0.475	0.004
Residuals	2.169	41	0.053			
Instruction Protocol ✻ Order of Visual Stimuli	0.562	1	0.562	8.885	0.005	0.084
Residuals	2.592	41	0.063			

Note. Type III Sum of Squares

Table 4 Repeated-Measures ANOVA for CV Data

Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p	η^2
Instruction Protocol	0.045	1	0.045	1.200	0.280	0.011
Residuals	1.561	42	0.037			
Order of Visual Stimuli	0.034	1	0.034	1.009	0.321	0.008
Residuals	1.421	42	0.034			
Instruction Protocol ✻ Order of Visual Stimuli	0.040	1	0.040	1.757	0.192	0.010
Residuals	0.946	42	0.023			

Note. Type III Sum of Squares

Two separate paired samples t-tests were conducted to look further into the conditions based on the instruction protocol and order of visual stimuli. The results of the paired samples t-test for the PSE data are displayed in Table 5. First, the PSE data for [S]-C and [C]-S were compared. These conditions followed the same instruction protocol but had a different order of visual stimuli. There was a significant difference for order of visual stimuli, $t(42) = -2.331$, $p = 0.025$, $d = -0.355$. The PSE data for S-[C] and C-[S] were then compared. These conditions also followed the same instruction protocol but had a different order of visual stimuli. There was a significant difference for order of visual stimuli, $t(41) = 2.015$, $p = 0.050$, $d = 0.311$. The PSE data for [S]-C and S-[C] were compared, which had the same order of visual stimuli but followed a different instruction protocol. The results indicated that there was no significant difference for instruction protocol, $t(42) = -1.104$, $p = 0.276$, $d = -0.168$. Finally, the PSE data for [C]-S and C-[S] were compared, which also had the same order of visual stimuli, but followed a different instruction protocol. This comparison indicated a significant difference for instruction protocol, $t(41) = 3.559$, $p = < .001$, $d = 0.549$.

A final paired samples t-test was conducted to compare the instruction protocol and order of visual stimuli per the CV data (see Table 6). The selected comparisons followed the logic described in the paired samples t-test conducted for the PSE data. First, [S]-C and [C]-S were compared, and there was not a significant difference in the order of visual stimuli, $t(42) = 0.082$, $p = 0.935$, $d = 0.013$. S-[C] and C-[S] were then compared, and the results showed no significant difference for order of visual stimuli, $t(42) = -1.333$, $p = 0.190$, $d = -0.203$. [S]-C and S-[C] were compared, and there was not a significant difference for instruction protocol, $t(49) = -0.051$, $p = 0.959$, $d = -0.008$. Finally, [C]-S and C-[S] were compared, and there was not a significant difference for order of visual stimuli, $t(42) = -1.657$, $p = 0.105$, $d = -0.253$.

Table 5 Paired Samples T-Test for PSE Data

Measure 1	Measure 2	t	df	p	Cohen's d
[S]-C	[C]-S	-2.331	42	0.025	-0.355
S-[C]	C-[S]	2.015	41	0.050	0.311
[S]-C	S-[C]	-1.104	42	0.276	-0.168
[C]-S	C-[S]	3.559	41	< .001	0.549

Note. Student's t-test.

Table 6 Paired Samples T-Test for CV Data

Measure 1	Measure 2	t	df	p	Cohen's d
[S]-C	[C]-S	0.082	42	0.935	0.013
S-[C]	C-[S]	-1.333	42	0.190	-0.203
[S]-C	S-[C]	-0.051	42	0.959	-0.008
[C]-S	C-[S]	-1.657	42	0.105	-0.253

Note. Student's t-test.

DISCUSSION

The purpose of the study was to gain a better understanding of the effects cognitive load has on judging durations. Instruction protocol and order of visual stimuli were used as methods of manipulating cognitive load across the same participants. The present study asked the following question: How does instruction protocol and order of visual stimuli as a method of cognitive loading affect the perception of time? To answer this question, a duration discrimination task was conducted in which the same participant pool was presented with two sets of instructions, and the visual stimuli were presented in a standard-comparison or comparison-standard order. It was hypothesized that the instruction protocol and order of visual stimuli requiring participants to hold temporal information in working memory and demanding increased attention would result in less accurate and less precise judgments of durations due to the high cognitive load produced. This would be evident in the PSE and CV data. It was predicted that the effects on time perception would be a function of attentional demands and memory that are fundamental to varying levels of cognitive load. The results of the present study failed to support the hypothesis, such that it revealed that instruction protocol and order of visual stimuli had effects on accuracy, but not precision, when performing the duration discrimination task.

Recall that, in time perception research, the PSE is a measure of accuracy, and the CV is a measure of precision. In the present study, a PSE value around 0.5 (i.e., 500 ms and the value of standard S), signifies more accurate duration judgments, as this indicates the probability at which the comparison stimulus is judged as equal to the standard stimulus (Vidotto, Anselmi, & Robusto, 2019). Furthermore, a lower CV value indicates more precise duration judgments, as this signifies less dispersion around the mean. While the average PSE and CV data did not reveal values that wavered from what is considered normal, there were significant differences that appeared in the PSE data when comparing performance based on instruction protocol and order of visual stimuli.

Looking first at the [S]-C condition, the average PSE indicated a slight underestimation of time, but the average CV indicated precision throughout the condition. In the [C]-S condition, there was a slight overestimation of time per the average PSE, but again, the CV data indicated precision throughout. The average PSE in the S-[C] condition indicated neither an underestimation nor overestimation of time, but the average CV indicated slightly worse precision than in [S]-C and [C]-S. Lastly, the average PSE for the [C]-S condition indicated a greater underestimation of time than seen in [S]-C and an average CV that indicated worse overall precision in comparison to all the other conditions.

It is essential to consider the cognitive load that was produced by each of the four conditions and how this possibly affected the accuracy and precision of the duration judgments. It was predicted that [C]-S and S-[C] conditions (low load) would be associated with better performance on the duration discrimination task. Alternatively, it was predicted that [S]-C and C-[S] conditions (high load) would be associated with worse performance on the duration discrimination task. Highlighting the PSE data, S-[C] had the best accuracy, followed by [S]-C, then [C]-S, and C-[S]. Overall, the S-C order of visual stimuli had the best accuracy, compared to the C-S order of visual stimuli.

Meanwhile, the CV data indicated that [C]-S had the best precision, followed by [S]-C, then S-[C], and C-[S]. Differences in precision for conditions following Instruction 1 were not seen, while any differences in precision for conditions following Instruction 2 were not significant.

To look further into the effects of instruction protocol and order of visual stimuli on the duration judgments, repeated-measure ANOVAs were conducted. A significant main effect of instruction protocol and a significant interaction between instruction protocol and order of visual stimuli was obtained in the PSE data. These results suggest that effects on accuracy when making duration judgments during the task were influenced by the presence of the instruction protocol, as well as the interaction between instruction protocol and order of visual stimuli. There was not a significant main effect of order of visual stimuli for the PSE data, meaning it did not impact accuracy. Also, there were no significant main effects or interaction obtained in the CV data, which suggests instruction protocol and order of visual stimuli did not influence precision when making duration judgments during the task.

As for the paired sample t-tests, there were three significant differences identified in the PSE data, but no significant differences in the CV data. Looking at the PSE data, it appeared that the order of visual stimuli was significant in the performance differences between [S]-C and [C]-S, as well as that of S-[C] and C-[S]. Likewise, instruction protocol was significant in the performance differences between [C]-S and C-[S]. However, there was not a significant difference between [S]-C and S-[C] based on instruction protocol, meaning that the use of instructions did not make a difference in performance when comparing these two conditions. Considering the results of both the repeated-measure ANOVAs and paired sample t-tests, the PSE data suggests that the combination of instruction protocol and order of visual stimuli, which were methods of manipulating cognitive load, had significant effects on the accuracy of time perception in the duration discrimination task. However, since there were no significant differences seen in the CV data, this suggests that the combination of instruction protocol and order of visual stimuli did not have significant effects on the precision of time perception in the duration discrimination task. Despite fluctuations in accuracy, participants were similarly precise in their duration judgments throughout the four conditions.

The significant results seen between conditions based on the order of visual stimuli were seen in previous studies. Specifically, it is suggested that the order in which the standard S stimulus is presented in sequence with the comparison C stimulus can influence the perception of time. This concept is known as the time-order effect (TOE) and can be further classified into Type A and Type B TOEs (Sierra et al., 2021). When the order of visual stimuli affects the PSE, this is known as a Type A effect. Meanwhile, when the order of visual stimuli affects the CV, this is known as a Type B effect. Based on the results of the present study, it appears there is a Type A effect occurring. This is consistent with the results of Sierra and colleagues' study, which found that the order of visual stimuli modulated temporal accuracy. The authors followed their experiment with a Bayesian model and determined that Type A effects arise due to sensory uncertainty.

In the present study, perhaps there was a level of uncertainty that potentially arose due to the order of visual stimuli changing between conditions. Notably, a study by

Aggarwal & Agarwal (2020) determined that high cognitive load has more uncertainty than low cognitive load. The authors employed a multiple object tracking (MOT) task with varying levels of uncertainty, which creates a high cognitive load and demands a high allocation of attention. Monitoring with EEG, the results of the study showed that an increase in cognitive load produces more fluctuations in the beta frequency band and increases uncertainty processing due to the attention-related processes. Likewise, a study by Coutinho and colleagues (2015) found that increased cognitive load hinders uncertainty monitoring, as it places demands on working memory. Uncertainty monitoring, as defined by the authors, is an adaptive method in which participants decline trials that they are unsure of to avoid errors that can result in negative consequences. As such, their study found that this ability to monitor uncertainty is reduced in the presence of a high cognitive load. While the results of these studies do not directly relate to cognitive load in time perception, there are implications for a line of future research. Specifically, the question remains as to how time perception is affected under levels of uncertainty and how this may correspond to time perception under high cognitive load.

Meanwhile, several past studies have shown Type B effects when conducting a duration discrimination task in different modalities (Dyjas, Bausenhart, & Ulrich, 2012; Ellinghaus, Ulrich, & Bausenhart, 2018; Gao et al., 2021). Indeed, a study by Bausenhart and colleagues (2015) found that a short interstimulus interval (ISI) of around 100 ms, but not a long ISI of around 1,000 ms, can diminish or eliminate the Type B effect typically seen in a duration discrimination task. The present study had a gap between the visual stimuli (i.e., an ISI) of 1,000 ms, yet the Type B effect was still not seen.

Additional past studies supported that discrimination performance decreases when the standard stimulus is presented second rather than first when compared to the comparison stimulus (Lapid, Ulrich, & Rammsayer, 2008; Gao et al., 2021). Specifically, a study by Ellinghaus, Ulrich, & Bausenhart (2018) determined that across various stimulus attributes, such as duration, frequency, intensity, and numerosity, and across visual and auditory stimulus modalities, a Type B effect emerges in discrimination tasks. The authors claimed that discrimination sensitivity (i.e., precision) was higher when the standard preceded the comparison stimulus rather than followed it. Likewise, the authors noted that this finding relates to the Internal Reference Model, which is a decision process where an internal reference is updated trial to trial based on previous and current stimulus instances. This finding is not consistent with the results of the present study, as the CV values were relatively similar across the conditions, with only the C-[S] condition having a marginally higher CV.

The question then remains as to why effects on the CV were not found in the present study. Perhaps the use of instruction protocol influenced these results. In the previous research described, participants were simply asked to determine which stimuli were longer in duration, with the stimuli modalities being either visual, auditory, or tactile. Additionally, the past studies did not inform participants which stimulus should be compared, such as in the present study. Participants were required to attend to both stimuli with the same weight. In the present study, this was not the case, as participants were instructed which visual stimuli to attend to for subsequent comparison to the other visual stimuli. Perhaps these distinctions led to fluctuations in accuracy on the task but did not modulate precision. Understanding this potential influence of instruction is critical. Recall that it was predicted the instruction protocol and order of visual stimuli that required participants to hold temporal information in working memory and demand increased attention would result in less accurate and less precise judgments of durations due to the high cognitive load produced. However, in the present study, it appears that instruction protocol might not be a cognitive loading factor and thus does not influence the precision of duration judgments. Perhaps having instructions regarding where to attend lessens the uncertainty of judging the durations, and therefore, led to the CV not being affected. However, by having the order of visual stimuli manipulated, there are still differences seen in accuracy. Further research needs to be conducted to understand the interaction between instruction protocol and order of stimuli on time perception and as cognitive loading factors.

Regarding future research, two additional duration discrimination tasks could be conducted. One experiment could focus on the order of visual stimuli being manipulated but without differing instruction protocol. Another experiment could focus on instruction protocol being manipulated but without the order of visual stimuli changing. This would provide further insight into how each of these cognitive loading factors directly affects the perception of time. Likewise, it would be wise to consider changing the language used in the instructions. As mentioned previously, past studies often asked which stimulus was longer, rather than was one stimulus shorter or longer than another stimulus. A study by Yates, Loetscher, & Nicholls (2011) revealed that researchers should use caution in how they ask participants to respond. Using words such as shorter, longer, bigger, or smaller can alter the observers' perception. The authors remarked that this has been seen in other ways throughout the literature, such that brighter stimuli are often perceived as longer in duration. Thus, it is critical to keep this phenomenon in mind when designing additional experiments, as this could potentially play a role in the differing results the present study has from past studies. These avenues for potential research highlight the limitations of the present study, as well.

Additional future research could use different stimulus modalities, such as auditory. Ivry & Schlerf (2008) remarked that auditory stimuli are often perceived as longer than visual stimuli. Wiener, Thompson, & Coslett (2014) also found that auditory stimuli are often perceived more precisely than visual stimuli, as indicated by lower CV values. It would be curious to see how stimulus modality may factor into the results of the present study or offer different conclusions. Finally, the present study could also be conducted with the use of EEG or MRI to identify activity in the brain associated with the duration discrimination task. Specifically, it would be noteworthy to measure activity in areas of the brain associated with holding temporal information, working memory, and attention. Perhaps this study could also extend to populations with known deficits in timing, such as persons with schizophrenia, Parkinson's disease, attention deficit hyperactivity disorder, or autism (Thoenes & Oberfeld, 2017; Allman & Meck, 2011).

The results of this study provide implications for real-world learning and task performance. As described previously, cognitive load interacts with human performance, such as on a Stroop task or operating a driving simulator. The results of the present study indicate the role of instruction protocol and order of visual stimuli on the accuracy of time perception. It appears, in this study, the addition of the instruction protocol mitigated any effects on precision when making duration judgments. Thus, conducting further research regarding instruction protocol as a method of lessening the cognitive load and its effects on time perception could assist in designing complex technologies and user interfaces designated for human use. Furthermore, this line of research may prove to be influential in refining models on human attention, learning, memory, and performance involving difficult tasks. As such, the results of the present study support the identification of methods to reduce error on high-load tasks where time perception is vital, such as operating a motor vehicle or working in a fast-paced environment.

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