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It's About Time: the Effectiveness of Time Perception as a Measurement of Cognitive Load

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IT’S ABOUT TIME: THE EFFECTIVENESS OF TIME PERCEPTION AS A MEASUREMENT OF COGNITIVE LOAD

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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

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This study examines the effectiveness of time perception as a measurement of cognitive load. The purpose of this research is to determine whether the concept of time perception can efficiently indicate high or low cognitive load in a task, and to compare this measurement to the standard mental effort rating scale that is typically used to measure cognitive load. In this study, participants completed both simple and complicated math problems at their own pace. After they were told to stop, participants either rated their level of mental effort used in the task, or wrote down how long they believed it took them to work on the math problems. Each participant completed both the simple and complicated math, as well as both of the measurements. The results indicated that time perception is an effective predictor of the level of cognitive load required of the math problems, and that this measurement is more sensitive than the mental effort rating scale.
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It's About Time: The Effectiveness of Time Perception as a Measurement of Cognitive Load

At present, only two primary measures of cognitive load have been identified. One of these measures is a self-report technique. This subjective measurement asks participants to rate the level of mental effort that is used to complete a task and is used to measure the level of cognitive load. The second way to measure cognitive load is to record the participant’s completion time for a given task. The goal of my research was to see if a mixture of these two measurements would result in an effective alternative to the techniques currently used to measure cognitive load. I wanted to investigate the use of time perception as a new means by which cognitive load can be measured. If successful, this research would provide psychologists with another, potentially more reliable, measurement technique to use while investigating topics related to cognitive load.

In order to properly study the construct of cognitive load, psychologists must first develop an efficient and effective measurement. The question remains, how can we accurately investigate manners of reducing or manipulating cognitive load when there has yet to be a universally agreed upon method of measurement? In order to provide a robust framework for this instructional design, there needs to be more research investigating new methods to measure cognitive load (Mayer & Moreno, 2003). Paas et al. (2003) reiterates this sentiment that “there is a clear need for tools to assess and predict cognitive load” (p. 64). The standard measurement for most psychologists is the mental effort rating scale. This scale asks the participants to rate on a scale of one to nine how much
mental effort they believe they used in completing the prior task. Self-report techniques, such as this one, are seen as the most reliable and unintrusive ways to measure cognitive load. However, researchers still have doubts with this measurement because not only is it a self-report technique, but also the measurement in its entirety is presented to the participant. This has the potential to allow certain biases to affect the subject’s answer. Specifically it allows for the confirmation bias because the participants know what the researcher is looking for and may choose to answer accordingly. Other methods of measurement for cognitive load include physiological measurements (heart rate variability and pupil dilation), and performance results such as number of errors and reaction time in a given task. Neither of these methods are frequently used.

In one of the most well known studies concerning cognitive load, Paas and van Merriënboer (1994) define this concept as a multidimensional psychological construct that assesses the mental effort, or load, that any task or situation requires of an individual’s cognition. An important facet of cognitive load research is Cognitive Load Theory (CLT). This theory is focused on the developing teaching and instruction methods that can utilize the information psychologist’s have from research on cognitive load, and then apply this to basic to learning methods. Specifically, CLT encourages people to use their prior knowledge and skills in new situations and problems (Paas et al, 2003). According to Paas et al (2003), there are three attributes that make up cognitive load as a whole: “intrinsic load, extraneous or ineffective load, and germane or effective load” (p. 65). Although these attributes are difficult to measure separately, intrinsic cognitive load is what we investigated. Intrinsic load is characterized by the interaction between the knowledge of the learner and the nature of the material, so essentially the level of
difficulty innate to the task. Paas et al (2003) states that this is the only attribute that is not directly affected by the design of a task or by the instructor themselves. In summary, intrinsic load is the most straightforward subsection of cognitive load, and the most relevant to the aspect we studied.

Another aspect of cognitive load that was investigated in the current study was mental effort. According to Paas et al (2003), “mental effort is the aspect of cognitive load that refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task; thus, it can be considered to reflect the actual cognitive load” (p. 64). Other aspects of Cognitive Load Theory such as performance were not of specific interest to the current study. Simply put, we were not interested in how well participants performed on the task, only how they measured the mental effort they used. Mental effort rating scales are used the most frequently to report cognitive load.

Typically, mental effort is rated on a self-report scale, assuming that individuals are able to “introspect on their cognitive processes” and report the degree of mental effort used (Paas et al, 2003, p. 66). In our study, we used this method of measurement as our control, or baseline, as this is a somewhat reliable measure that is used in the majority of research previously done in this subject.

An interesting topic that we investigated is the concept of subjective time perception. This has only been looked at in terms of cognitive load in one other study. In this study from Fink & Neubauer (2000) researchers looked at cognitive load and its relationship with time perception, but in terms of intelligence. Their purpose was to “offer an explanation for the IQ-mental speed relationship” (p. 1010). Theoretically, time perception could be used as an effective measurement for cognitive load because as Fink
& Neubauer (2000) assumed, “as nontemporal task demands increase, less attention is left to process temporal information, and the estimated duration of a given time interval becomes more inaccurate” which could be viewed as a scale with which to measure levels of cognitive load (p. 1010). The harder the task and the more mental resources it uses, the more inaccurate the time perception becomes. Essentially, if the inaccurate subjective time estimations follow a pattern, and either increase or decrease with the level of mental resources being used, we can infer that the perceived time estimations are not only related to but also indicative of cognitive load. When used in studying cognitive processing, experimenters theorized that the perceived duration of a task is directly related to the storage size of the interval or information given (Thomas & Weaver, 1975).

In short, the larger the storage size of the task at hand, the more it affects the processes related to time perception. Conversely, this theory can be adapted to the current understanding of cognitive load. The ‘perceived duration’ of a task could be directly related to the level of cognitive load and mental effort exerted in the completion of the task, as mentioned above.

Time perception, though, can be measured in many ways. The study by Fink & Neubauer (2000) had participants hold down a button for the amount of time they believed it took them to complete a task. In other words, the participants would hold down a key for the perceived duration of the task, and researchers measured this time length. We aimed to use a more straightforward and simple measurement of subjective time perception, instead of the more complicated forms that have been used in the past. According to Brown (1985), “verbally estimated durations are usually longer and/or more inaccurate than time judgments ascertained by means of the reproduction method” so we
decided upon using the written reproduction method (p. 1011). Instead of verbally reporting their subjective time estimation, subjects in our study would write down how long they believed it took. It is important to note that we did not inform the participant of the measurement estimation until after they completed the task.

The purpose of the current study is to investigate subjective time perception as an effective measurement of cognitive load. Time perception offers an indirect method, in which the participant retrospectively writes down how long they believed it took them to complete the task at hand. This is an unintrusive and simple measurement that, if successful, can provide researchers with an effective and sensitive way to measure levels of cognitive load. We hypothesize that subjective time perception will be sensitive to the two different levels of cognitive load (high vs. low). Specifically, higher levels of cognitive load will lead to longer reported time perceptions, and lower levels will be indicated by shorter reported time perceptions.
Method

Participants

There were 63 participants in this study. Participants were students enrolled at the University of Mississippi and participated for either course credit or extra credit in their General Psychology classes. The participants signed up for the study using the web-based program Sona-Systems.

Materials

The first part of the study was a slideshow on the computer that consisted of 130 double-digit addition and subtraction arithmetic problems. This was labeled “Phase 1” and represented the simple arithmetic portion of the study. The complicated arithmetic segment was named “Phase 2”, and was also a slideshow. Phase 2 consisted of 130 double-digit by double-digit multiplication problems. While working through the problems in the slideshows, participants recorded answers on a sheet of paper given to them by the researcher. This answer sheet consisted of 105 blanks for the participants to write their answers. On the back of these sheets were the self-report measurements. There were two different measurements each participant completed during the course of their session. One of the measurements was a 9-point scale rating the level of mental effort the participant used to solve the math problems (Appendix A). This scale ranged from 1 (Very, very low mental effort) to 9 (Very, very high mental effort) (Paas, 1992). The second measurement was the Subjective Time measurement. For this self-report technique, after completing the task, the participants wrote down in minutes and seconds how long they believed it took for them to solve the set of math problems (Appendix B).
When analyzing the data, the time perception was converted into seconds for a more uniform measure.

Procedure

Participants took part in one of four conditions. The participant was not aware of the time perception measurement and was only instructed to work on the math problems they could see on the screen. Each set of arithmetic problems were on a slideshow, therefore the participants were able to move on to the next problem at their own pace. For both the simple and complicated arithmetic slideshows, participants were told to work until they were told to stop by the assistant, who stopped all participants at the five-minute mark. Because this was a within-subjects design, all participants completed both the simple arithmetic and the complicated arithmetic conditions in the same session. Depending on the condition, some participants completed the simple task before the complicated task, and others completed the complicated before the simple. After completing as many of the math problems as they could in the span of five minutes, the subjects, once again depending on their condition, either rated how long they believed it took them to do the problem (time perception measurement), or rated how much mental effort they believe they used in completing the math problem (Cognitive Load measurement). Everything was then repeated, with the participant completing whichever Phase (simple or complicated arithmetic) they had not done yet. So if they completed the simple arithmetic in the first section of the study, the participant the completed the complicated arithmetic. This was followed by whichever measurement they had not reported yet. After the subject completed both math problems and both forms of measurement, the experiment was over. In total this experiment took at a maximum about
30 minutes to complete, and each participant was awarded one research credit hour in the Sona-System.

The independent variable that changed from participant to participant was the order and pairing of the arithmetic with the measurement. The dependent variable of interest was how well the time perception measurement matches with the mental effort measurement. The control in this study was the math in each phase and the amount of time given to work on the arithmetic. Thus, the study represented a 2 (arithmetic type) X 2 (cognitive load measure) within subjects design:

1: Simple Arithmetic >> Time Perception; Complicated Arithmetic >> Cognitive Load Scale

2: Simple Arithmetic >> Cognitive Load Scale; Complicated Arithmetic >> Time Perception

3: Complicated Arithmetic >> Time Perception; Simple Arithmetic >> Cognitive Load Scale

4: Complicated Arithmetic >> Cognitive Load Scale; Simple Arithmetic >> Time Perception
Results

In order to confirm that there were no order effects that may have skewed the data, four different independent sample t-tests were run. The first compared the order effects of the simple arithmetic, Phase 1, and the time perception measurement. No significant order effects were found, $t (29) = 1.14, p > .05$. The second Independent samples test we ran looked at the complicated arithmetic, Phase 2, and the time perception measurement. This test found no significant order effects between them, $t (28) = .78, p > .05$. We then ran a third $t$-test testing the order effects between the simple arithmetic, Phase 1, and the mental effort rating scale, and this test was not significant, $t (28) = .07, p > .05$. The fourth and final $t$-test we ran to rule out order effects compared the complicated arithmetic, Phase 2, with the mental effort rating scale. As with all of the other Independent sample tests previously mentioned, there was no significance, $t (29) = -.86, p > .05$. From the insignificance of the data, we can assume there were no order effects in the study, indicating that the order the trials were presented, and the fact they were repeated, as a within-subjects design had no significant effects on the data.

An independent samples $t$-test was used to determine the difference in retrospective time estimation, comparing Phase 1 (easy arithmetic), to Phase 2 (hard arithmetic). We converted the participants’ time report into seconds, and used that number as the measurement. The results were found to be significant, $t (59) = -3.38, p < .01$. These results support our hypothesis that time perception is sensitive to the level of cognitive load. Another independent samples $t$-test was run to determine the difference in retrospective mental effort ratings. The numbers were on a scale of one to nine, nine
being the highest possible amount of mental effort used. These results were found to only be marginally significant, $t(59)=1.74, p=.09$.

Correlations were also used to compare the retrospective time perception measurement and the retrospective mental effort rating. Interestingly, there were no significant correlations between the two measurements. This could be explained by the difference in significance between the two measurements. The difference in levels of significance between the two measurements could explain why there were no significant correlations between the methods. The mental effort rating scale was found to be marginally significant, and the time perception measurement was found to be significant.

In conclusion, our results suggest that subjective time estimation is an effective way to measure levels of cognitive load, and this measurement was also more statistically significant than the commonly accepted self-report rating scale for mental effort.
Discussion

Our initial hypothesis stated that subjective time perception would be an efficient and effective indicator of cognitive load. As a part of the hypothesis, this measurement would be more sensitive to the high and low levels of cognitive load, by using an alternative method of measuring the level of mental effort required. The results from this study indicate that time perception is in fact a significant predictor of cognitive load. According to the significance of the results, when participants self-reported how long they believed they were working on the arithmetic, the differences in perceived time diverged greatly between conditions of arithmetic. In general, participants reported longer times after working on the complicated section, indicating high cognitive load. Conversely, shorter times were reported after the simple arithmetic section. The difference between the simple versus complicated time estimations is visible in Graph 1. Possible reasoning for why this happens, as stated in the introduction, is that perceptively, time might pass slowly when the subject is expending more mental effort and cannot use any mental resources to keep track of less important topics such as time. Therefore, the participants in our study were devoting all of their cognitive facilities to solving the math problems, leading to high levels of cognitive load. As theorized by Fink & Neubauer (2003), the less attention available to devote to time related tasks, the more inaccurate the time estimation. Therefore, in our study, we assumed and found that the harder the task, requiring more cognitive effort and resources, the longer the perceived time duration. Our results support our initial hypothesis. The difference between retrospective time
estimations was significant, and sensitive to whether there was high or low cognitive load.

Interestingly enough, our results also found that the retrospective mental effort scale was not an accurate indicator of the level of cognitive load. Graph 2 shows the difference in simple versus complicated mental effort ratings. Our results were only marginally significant, which is important because this is the measurement most commonly used to empirically measure the construct of cognitive load. This indicates that the mental effort rating scale was not as effective in measuring the level of cognitive load. In an attempt to compare the two measurements, time perception and mental effort, we ran correlations and found no significance.

Even though the correlations we ran were not significant, this result still has importance. The lack of a correlation between the mental effort scale and the time perception measurement could be explained by looking at our other results. The independent samples test we ran measuring the difference between the retrospective time estimation was significant, meanwhile the same test we ran measuring the difference between the retrospective mental efforts only had marginal significance. These two measurements may not have been correlated because only one of them showed significant results. It is possible that the mental effort scales were not found to be significant or effective, which is why it cannot correlate with the time perception rating. This result is beyond what we predicted in our hypothesis, and further supports the time perception measurement as a means of indicating cognitive load.

Previous literature in this field has not investigated alternative measures of cognitive load. While multiple studies have mentioned that time perception should be
researched, only one has attempted this. That study by Fink & Neubauer (2000) looked into the link between intelligence, speed, and cognitive load. Our study aimed to not only investigate the effectiveness of time perception as a measurement of cognitive load, but also to compare it to the standard method of measurement, the self-report rating scale for mental effort. In order to understand the construct of cognitive load and learn how to manipulate it, first and foremost, there needs to be an effective and efficient empirical measurement. For decades the self-report mental effort scale technique has been the trusted and most used measurement of cognitive load, but many of the psychologists doing this research have expressed skepticism with the current selection of measurement tools at their disposal, even with the self-report scale. Paas et al. (2003), noted that “there is a clear need for tools to assess and predict cognitive load” in his article that presented all current methods for measurement, including the self-report mental effort scale (p. 2). The mental effort scale is effective, but to what extent? If the participants know what it is that we are attempting to measure, this knowledge could lead to possible bias. An example would be the confirmation bias, as is the risk with most self-report techniques. The time perception measurement serves as an indirect self-report technique. By asking the participants how much time they spent on a task, the researcher does not reveal any information about the measurement. This could lead to a more reliable and valid measurement. The present study has helped to establish subjective time perception as a new way to measure the differing levels of cognitive load, and has contributed to the limited amount of empirical research in the field concerning Cognitive Load Theory.

It is important to note that our study had a few limitations that may have affected the results. First, our study was limited because of its small sample size. The sample size
could have expanded with more time available to run the study. Ideally a larger sample would have been even more beneficial, but due to the within subjects design of the study the data was effectively doubled as we tested both measurements and both levels of arithmetic on the subjects.

Additionally the participants’ prior knowledge could be seen as a limitation. Participants who have more knowledge of and practice with arithmetic could have perceived the times to be shorter on both ends. However, our data significantly indicates that it seemed to take longer to complete the complicated arithmetic, so this limitation did not have any large effect on our study.

In conclusion, our hypothesis predicted that estimated time perception could serve as an effective measurement of cognitive load, and our results supported this prediction. Even further, our results also compared the standard measurement for cognitive load, mental effort rating scales, to the time perception measurement and found that the standard measurement is not as sensitive to the levels of cognitive load. Future studies should examine in more detail the relationship between subjective time estimation and cognitive load. More research needs to be done to validate this measurement before it can be used as psychometric tool, but for now our study brings to light the importance of finding a new and more effective form of measurement for cognitive load, and also provides one alternative way to measure this.
REFERENCES


Graph 1

Time Estimation Graph

![Time Estimation Graph](image_url)
Graph 2

Mental Effort Graph
Appendix A

*Mental Effort Rating Scale*

Please rate the level of mental effort you used to solve the math problems.

1. Very, very low mental effort
2. Low mental effort
3. Average mental effort
4. High mental effort
5. Very, very high mental effort
Appendix B

*Time Perception Measurement*

How long do you believe it took you to solve the set of math problems (in minutes and seconds)?

______ minutes

_______ seconds