Measuring the Impact of Subtitles on Cognitive Load: Eye Tracking and Dynamic Audiovisual Texts

Jan-Louis Kruger
North-West University
Vaal Triangle Campus
JanLouis.Kruger@nwu.ac.za

Esté Hefer
North-West University
Vaal Triangle Campus
Este.Hefer@nwu.ac.za

Gordon Matthew
North-West University
Vaal Triangle Campus
20684886@nwu.ac.za

ABSTRACT

In educational design literature, it is often taken as fact that subtitles increase cognitive load (CL). This paper investigates this assumption experimentally by comparing various measures of CL when students watch a recorded academic lecture with or without subtitles. Since the measurement of cognitive load is by no means a simple matter, we first provide an overview of the different measurement techniques based on causality and objectivity. We measure CL by means of eye tracking (pupil dilation), electroencephalography (EEG), self-reported ratings of mental effort, frustration, comprehension effort and engagement, as well as performance measures (comprehension test).

Our findings seem to indicate that the subtitled condition in fact created lower CL in terms of percentage change in pupil diameter (PCPD) for the stimulus, approaching significance. In the subtitled condition PCPD also correlates significantly with participants' self-reported comprehension effort levels (their perception of how easy or difficult it was to understand the lecture). The EEG data, in turn, shows a significantly higher level of frustration for the unsubtitled condition. Negative emotional states could be caused by situations of higher CL (or cognitive overload) leading to learner frustration and dissatisfaction with learning activities and own performance [16]. It could therefore be reasoned that participants had a higher CL in the absence of subtitles. The self-reported frustration levels correlate with the frustration measured by the EEG as well as the self-reported engagement levels for the subtitled group. We also found a significant correlation between the self-reported engagement levels and both the short- and long term comprehension for the unsubtitled condition but not for the subtitled condition. There was no significant difference in either short-term or long-term performance measures between the two groups, which seems to suggest that subtitles at the very least, do not result in cognitive overload.

Categories and Subject Descriptors

J4 [**Social and Behavioural Sciences**]: Psychology.
J5 [**Arts and Humanities**]: Language translation.

General Terms

Measurement, Performance, Reliability, Human Factors, Languages.

Keywords

Cognitive load; educational design; eye tracking; change in pupil diameter; EEG; dynamic audiovisual texts; subtitles.

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1. INTRODUCTION

The impact of subtitles on cognitive load (CL) is a potentially contentious issue with conflicting evidence on whether or not subtitles increase CL. It is sometimes suggested that subtitles not only increase CL, but create cognitive overload (CO). Should this be true, it would mean that adding text in the form of subtitles to a video recording of, for example, a lecture, would necessarily result in a reduction in deep learning or long-term schemata formation. However, although subtitles undeniably result in a distribution of attention between different sources of information, it is not a given that this distribution results in split attention that reduces performance or causes overload. If students spend only as much time on each source as needed then theoretically their attention is distributed, or allocated sequentially and not split. Likewise, the matter of redundancy that could result in poor performance [5] is not a given. If students can successfully integrate what they hear with what they see, it may result in supplementing of information rather than redundancy.

Although there are many theories on the impact of subtitle reading and CL, very few empirical studies have been conducted to measure CL in the presence of subtitles. The current study set out to measure CL, and also to examine the impact of subtitles on CL (whether subtitle reading results in increased CL or CO, and which measures can be used to measure CL reliably in this context).

2. COGNITIVE LOAD THEORY

CL is considered to be a theoretical construct describing the internal processing of tasks that cannot be observed directly [12]. According to literature, CL can be subcategorised into three distinct segments, namely intrinsic, extraneous and germane cognitive load [12]. Intrinsic cognitive load is caused by the appearance of the material and how difficult it is to understand and it cannot be manipulated. Extraneous cognitive load is created by the way the information is presented (e.g. video with or without subtitles). Germane cognitive load constitutes the remaining available cognitive resources, or the CL that people use to process and comprehend material, and to form schemata. The higher the intrinsic and or the extraneous load, the less capacity remains in working memory for germane cognitive load before CO sets in.

With regard to measurement, CL can be conceptualised in three dimensions, namely the mental load, mental effort and the performance of the participant [4]. The category of mental load can be imposed by the task or environmental demands that relate to the difficulty of the task or the environment in which the task is being completed. Mental effort, in turn, can be defined as the total amount of controlled cognitive processing in which a subject is engaged [25]. Measures of mental effort can provide information on the cognitive costs of learning, performance or both [25]. Finally, the level of performance can be established by a post-task test where amount of correct answers will serve as an indication of performance. The combination of performance and mental effort is considered to be the best indicator of CL [4].

In educational design subtitles are assumed to increase extraneous CL [11], [18], [23]. At the very least, it is suggested that since subtitles increase extraneous or ineffective CL, it results in a reduction in germane or effective CL that is responsible for the formation of schemata. In other fields, like language acquisition, subtitles are regarded to decrease extraneous cognitive load, thereby increasing germane CL since it is deemed to impact positively on performance measures [17]. In the current study, where the context is same language subtitling (SLS – English to English) for students studying through medium English as a second language (ESL), eye tracking will be used in conjunction with performance and mental effort (in the form of self-report questionnaires), as well as EEG data, to determine the CL while reading subtitles. This should provide more information on whether subtitles used in this context increases or decreases CL.

3. MEASURING COGNITIVE LOAD

The classification used in the current study is based on the concepts of objectivity and causal relationship, in which there are objective and subject ways of measuring CL directly and indirectly [12].

Eye tracking (ET) measurements fall into the indirect and objective categories and as such, they are considered reliable measures of CL [26]. However, typical eye-tracking measures such as mean fixation duration and fixation count are less useful in the context of a combination of very different tasks such as visual search and reading, with reading eliciting more, shorter fixations due to the reading process and not because of load. A more stable data source for this context is pupil dilation, making it possible to determine the percentage change in pupil diameter (PCPD). PCPD can be categorised as an objective direct measure of CL, and along with other physiological measures such as EEG, heart rate, blink rate and blood pressure, it is considered one of the most precise measures of CL [24].

EEG is a physiological index that can serve as an online, continuous measure of brain activity that detects subtle fluctuations in CL. This can help explain such changes in CL when other measures fail to reflect differences in cognitive processing [19].

Self-report measurements are also considered reliable sources of CL [12]. Self-reported mental effort can be classified as an indirect and subjective measure, whereas frustration levels and comprehension effort can be classified as direct and subjective measures of CL.

Finally, the achievement of learning outcomes provides an indirect but objective measurement of CL as a performance measure. In this study, a validated post-hoc comprehension test was used.

All measures used in the current study are presented in Table 1 that is derived from the work of Brünken et al. [12].

4. PUPILLOMETRICS

The use of pupil size as an indicator of cognitive processes dates back to the 1800s, and since the 1960s, there have been many studies into the behaviour of the pupil in cognitive psychology [22]. Many pupillometric studies have suggested that there is a link between pupil size and CL, with increase in dilation indicating higher cognitive demand [28].

Many pupillometric studies have investigated reactions to interactive tasks, such as the memorisation of digit sequences [27], mental multiplication [1], aural vigilance [15], as well as interpreting and translation [8], [20], [21]. In all of these studies, pupil size was shown to be a reliable indicator of task difficulty. While some researchers had success in studies using pupil size as a measure of cognitive effort during, for example, the translation process with the translation memory tool [20], others did not find it a reliable measure of cognitive effort when, for example comparing texts of varying levels of difficulty [28].

Table 1. Classification of methods for measuring CL

	Causal relation	
Objectivity	**Indirect**	**Direct**
Subjective	Self-reported mental effort	Self-reported frustration levels
		Self-reported Comprehension effort
Objective	Eye-tracking	EEG- measurements
	Comprehension test	PCPD

A baseline figure is generally used to determine the change in pupil diameter while carrying out a certain task. This change is then expressed as a percentage of the baseline figure. Generally speaking, the higher the PCPD, the more cognitive effort is likely to have been required. In the current study, the baseline was determined by calculating the average pupil diameter of participants while reading an instruction screen preceding the stimulus. This baseline was then subtracted from the pupil size measurement while watching the stimulus to arrive at comparable PCPD measurements for all participants.

Despite its advantages, the use of pupillometrics also has its disadvantages, since pupil size can be affected by numerous external factors. Some of these factors include gender, anxiety, taste, habituation, schizophrenia, arousal, novelty, light fluctuations, etc. [9]. In order to eliminate fluctuations in luminosity during the presentation of the stimulus as a confounding variable in the current study, a light meter was used to determine the variations in luminosity throughout the stimulus. An increase in luminosity was observed when the PowerPoint® slides were shown (900+ flux) compared to the rest of the stimulus (lecturer and classroom) where the luminosity was between 650 and 720 flux (subtitles did not affect luminosity). The absence of variation in luminosity within the two main conditions (PowerPoint® and lecturer) can be ascribed to the relatively stable image of the lecturer and the overall stability of the stimulus.

To control for the effect of the increased luminosity of the PowerPoint® slides, it was decided not to take into account the PCPD when the slides were presented when calculating the average PCPD for the screen. This was also done in the case of the subtitles (i.e. the PCPD for subtitles that coincided with the slides were excluded when calculating the average PCPD for the subtitles).

5. ELECTROENCEPHALOGRAPHY

At present, it is believed that electrical activity in the brain generates at least four distinct rhythms [3]. Two of these oscillatory components (rhythms), namely alpha and theta, of the continuous EEG have been reported as sensitive to task difficulty manipulations [6], [13], [14].

The general consensus is that the localization of recording sites is determined by where these brain wave rhythms are most prominent – parietal areas for alpha and frontal midline location for theta [14]. Measurement of the changes in the alpha and theta brain wave rhythms reflects what is happening in the participant's information processing situation, even if the participant is unaware of the changes or is unable to verbalize them [3], [10]. Therefore, when a person is frustrated, their mind emits a particular pattern of brain waves that is picked up by the EEG. The algorithms in the software interpret this pattern and give a graphical representation that indicates that the person was indeed frustrated.

An abundance of machine learning classification approaches are being used in EEG research to determine these emotional outputs. Examples thereof include: K-nearest neighbour algorithm, Support Vector Machines (SVM), multilayer perceptron (MLP), Logistic Regression, Decision Trees, Naïve Bayes. These classification approaches as well as numerous features of raw EEG data are incorporated in order to create a model of human academic emotion (e.g. boredom, confusion, engagement and frustration) [10].

In this study we did not use the raw data for interpretation but relied solely on the output given by the Emotiv software. As in the case of PCPD, a baseline (derived from EEG values while participants watched the instruction screen) was used to determine the change in values for the various EEG-channels.

6. METHODOLOGY

6.1 Participants

A convenience sampling method was employed to select Sesotho first-language students from the Vaal Triangle Campus of the North-West University, who study through medium English as a second language (ESL). A total of 46 participants were initially tested, but after excluding invalid data sets, 41 participants remained. Data sets were excluded based on whether participants' eye movements had been sufficiently tracked. For this, an eye-tracking ratio of 80% was used as cut-off point.

6.2 Materials

The materials used in this study include a biographical questionnaire, a video recording of a Psychology lecture, a comprehension test and a self-report questionnaire on task load.

The **biographical questionnaire** was used to collect basic information on participants and to control for confounding variables such as age, field of study, existing subject knowledge of Psychology, etc.

The primary stimulus shown to participants was a 14 minute segment of a **video recording of a first-year Psychology class**. The lecture was presented in English, and was presented to participants either with or without English subtitles, depending on the group they'd been assigned to randomly. One group watched the recorded lecture without subtitles (Group E); the other group watched the recorded lecture with English subtitles (Group EE). The subtitles were produced using Screen's Poliscript™ subtitling software. A maximum of two lines were used, with a maximum of 37 characters per line. Subtitle presentation rate was set at 120 words per minute (wpm). In practice this means that the subtitles present a near-verbatim transcription of the lecturer's words, synchronised with the spoken words according to established subtitle parameters.

The **comprehension test** was issued to assess participants' understanding of the content of the lecture, as well as being an objective indirect measure of CL, and consisted of 20 multiple choice items with an item reliability index of .9 that participants could answer in their own time. The questions consisted only of elements mentioned by the lecturer, such as definitions and examples. The same test was administered twice: directly after participants watched the stimulus, or Test 1 (to measure short-term memory), and approximately two weeks later, or Test 2 (to measure longer-term memory).

The **self-report questionnaire on task load** used in the current study was compiled from questionnaires generally used to determine the mental effort involved in completing specific tasks [2], [7], [26]. In the current study, the self-report questionnaire was issued in order to determine the participants' own perceptions of the effort involved in viewing the lecture.

6.3 Design

This study followed a quantitative experimental model, using a two-group (one test group, one control group) testing design. Participants' behaviour, attention distribution and brain activity was monitored while watching the stimulus (a video recording of a lecture) with or without subtitles, and their comprehension was tested directly after watching the stimulus and again after a period of two weeks. The **dependent variables** for this study were eye-tracking measures (percentage change in pupil diameter, dwell time %), EEG data (engagement/boredom, excitement, frustration), participants' responses to the self-report questionnaire on task load and their scores on the comprehension test. All eye tracking data were measured and analysed according to the areas of interest (AOIs) as marked in the stimulus (the lecturer, the PowerPoint slides, the subtitles and the rest of the screen). The **independent variable** for this study was the condition (test or control), whether the recorded lecture was viewed with or without subtitles.

Normally distributed data were analysed using descriptive and inferential statistics. Data that were not normally distributed were analysed using non-parametric statistics (Mann-Whitney U test). Correlations and t-tests were administered to determine the impact of subtitling on CL, the reliability of the measures and to assess whether subtitles create cognitive overload. The cut-off points for statistical significance were set at $p<0.05^*$ (statistical significance) and $p<0.01^{**}$ (highly significant).

6.4 Procedure

An SMI iViewX™ RED eye-tracking system was used to monitor participants' eye movements while watching the stimulus. The RED system is a dark pupil system using the pupil/corneal reflex method. It has a sampling rate of 50 Hz, and calculates the pupil position, pupil size and relative head movement. Minimum fixation duration was set as 80 ms, with 100 px as maximum dispersion. An Emotiv™ EEG was used to gather EEG while participants' eye movements were being tracked.

All participants were tested individually. They were seated comfortably in a sufficiently illuminated room, on a stable chair at a distance of 700 mm from the stimulus screen. As soon as participants were seated, the EEG was placed on their heads and checked for valid signal and data recording before starting with the experiment. An instruction page was displayed on the screen prior to the experiment stimuli. The eye tracking and EEG data gathered during the reading of this page was used as baselines for analysing PCPD and the various EEG measurements (excitement, engagement/boredom, meditation and frustration).

7. RESULTS

This study set out to answer the following research questions:

- What is the effect of subtitles on cognitive load?
- How reliable are the measures?
- Does subtitling create cognitive overload?

7.1 The effect of subtitles on cognitive load

Between the two groups, E and EE, there was a significant difference for PCPD on the stimulus as a whole (U = 178.00, z = 2.06, p < .05) with the groups that did not see the subtitles (E) registering higher CL (See Figure 1). A further interesting point is that there was no significant difference between the PCPD when participants in group EE looked at the subtitles and when they looked at the lecturer, indicating a similar CL for both activities.

With regard to the EEG data, the group that saw the stimulus without subtitles registered a significantly higher frustration level than the group that saw the subtitled version (U = 111.00,

z = 2.07, $p < .05$) (see Figure 2). No other difference in measures of CL was found for the two groups.

7.2 Reliability of measures of cognitive load

For group EE there is a positive correlation between PCPD on the screen and the EEG measurement for long-term excitement (r = .45, $p < .05$) and short-term excitement (r = .53, $p < .05$). In the case of the PCPD for the subtitles, there were similar positive correlations with the EEG measures for excitement levels. Furthermore, there were positive correlations between the self-reported comprehension effort for this group and the PCPD for the whole screen (r = .46, $p < .05$), the PCPD for the lecturer (r = .43, $p < .05$) and the PCPD for the subtitles (r = .47, $p < .05$).

For group E, there was a significant negative correlation between the EEG short term excitement and the self-reported comprehension effort (r = -0.57, $p < .05$), but no correlations between the PCPD measures and the other measures.

7.3 Subtitles and cognitive overload

There were no significant differences between the two groups in terms of the comprehension test results. This was the case for Test 1 (t (44) = .74, $p > .05$) and also Test 2 (t (33) = .41, $p > .05$).

For group E there was a positive correlation between Test 1 and Test 2 (r = 0.47, $p < .05$). There was also a correlation between self-reported engagement levels and Test 1 (r = .80, $p < .05$) as well as Test 2 (r = .52, $p < .05$).

8. FINDINGS

8.1 The effect of subtitles on cognitive load

Surprisingly, and in direct conflict with most literature on educational design, there was a significant difference in CL between the two groups as indicated by the percentage change in pupil diameter (PCPD) with the unsubtitled condition creating higher CL. This, combined with the fact that the unsubtitled stimulus also resulted in significantly higher frustration levels as measured by means of EEG, seems to suggest that same-language subtitles in an educational context where students learn through medium ESL reduces CL, which could be ascribed to the high intrinsic CL and the support provided to these students by subtitles. The fact that none of the other measures of CL registered significance difference between the two groups further supports the fact that the subtitles did not increase the CL as expected.

8.2 Reliability of measures of cognitive load

Particularly for the subtitled group, the interaction between different measures of CL in the objectivity and the causal categories supports the use of a combination of measures for reliable indications of CL. For this group the eye-tracking measure of pupil diameter correlated strongly with the EEG measures for excitement as well as with self-reported comprehension effort. The fact that the group that saw the stimulus without subtitles had a negative correlation between EEG measure for short term excitement and self-reported comprehension effort but no other correlations would suggest that the combination of measures serve to make a distinction between different dimensions of CL. This may bring us a little closer to a distinction between extraneous and germane cognitive load.

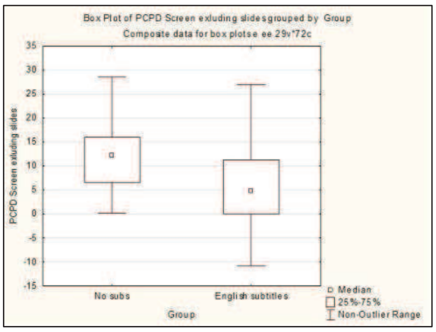

Figure 1. PCPD as measured across the groups

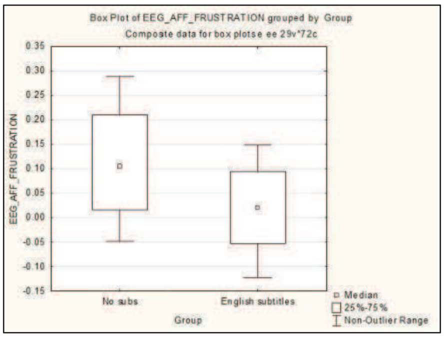

Figure 2. EEG frustration as measured across the groups

8.3 Subtitles and cognitive overload

None of the results support the hypothesis of cognitive overload in the presence of subtitles.

9. CONCLUSION

Even though this experiment was conducted in a very specific context in terms of the mother tongue of students and the language of instruction, the findings provide some compelling evidence in support of the use of subtitles in an educational setting to manage CL. In terms of the impact of subtitles on CL, it was found that the use of same-language subtitles in an educational context where students learn through medium ESL seems to reduce CL and does not lead to CO as some theories would suggest. In other words, the presence of subtitles provided students with support that facilitated their processing and understanding of the stimulus presented to them. The students who saw the stimulus without subtitles did not have this support and was found to experience higher CL. Furthermore, the use of eye tracking measures in combination with EEG data, self-report scales and performance data proved to provide a nuanced picture of the CL when subtitled audio-visual texts are processed.

As was mentioned at the start of this paper, there are many theories on the impact of subtitle reading and CL, but very few empirical studies have been conducted to measure CL in the presence of subtitles directly. The current study set out as a first empirical effort to do this, and as such we recognise that the study is slightly limited. Further investigation is needed into the use of subtitles in different educational settings (different subjects, different user groups, different languages, etc.) and with larger participant groups to make more conclusive statements. However, the findings of the current study represent the first steps towards truly understanding the impact and implications of using subtitles in an educational context.

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