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The Impact of Syntactic Processing in Sentence Comprehension on Cognitive Load Using the Measure of Heart Rate

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Cognitive load (CL) has been shown to induce changes in heart rate (HR) when exposure stimuli are designed as cognitive tasks, such as stroop, chemical equation tasks. The present project examined whether fluctuations in heart rate serve as an efficient indicator of the CL induced by syntactic processing during sentence comprehension "linguistic task". This was investigated by exposing a female second language user to syntactic violations and well-formed sentences, on the basis that ungrammatical items would create a cognitive overload, leading to an increase in the HR. After examining the participant's reactions to the two types of sentences, no difference was found in HR recordings between grammatical and ungrammatical conditions. However, the study was subject to limitations, and so further research is necessary to verify these initial results in the future.

Keywords: cognitive load, heart rate, grammatical, ungrammatical, sentence

Introduction

The theory that cognitive load (CL) arises when the limits of available processing power are reached (Sweller, 1988) suggests that when the CL required to complete a task exceeds the available working memory, then comprehension and learning are seriously impaired (Cranford, Tiettmeyer, Chuprinko, Jordan, & Grove, 2014). The principle here is assumed to be identical to the processing that takes place in computers; when running excessive processes simultaneously, task completion slows down and the machines can even crash.

In psychophysiological research, cognitive processing has been shown to influence HR (Fredericks, Choi, Hart, Butt, Mital, 2005; Mulder, 1992). It is assumed that when CL rises to "overload", the stress on the body also rises, resulting in physiological fluctuations measurable as changes in heart rate (HR) (Ikehara & Crosby, 2005). Thus, HR has been employed as an indicator of CL in experiments both in the field and in laboratory settings. The idiosyncrasy of such a measure is that it can provide real time data, and ensures a high level of objectivity relative to other types of measures (Fredericks et al., 2005; Mulder, 1992).

An enormous volume of empirical studies has investigated the impact of various cognitive tasks (e.g., Chemical equations, mathematical equations, and stroop tasks) on CL (Prada, Glanner, Nóbrega, & Córdova, 2010; Boutcher & Boutcher, 2006; Cranford et al., 2014). All of these support the existence of a relationship between CL and HR. Additional empirical studies (e.g., Kello, Plaut, & MacWhinney, 2000; Kerstholt, 1994; Sharma & McKenna, 2001) have revealed time pressure which can serve as a further stressor, playing a crucial

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role in judgments and decision making, resulting in cognitive overload and increasing the HR.

In the case of linguistically-induced cognitive load research, a considerable number of studies have been conducted to examine the role of CL in language processing, using measures such as ERP, fMRI, performance technique, and subjective techniques (Park, Kang, Choi, & Lee, 2013). In ERP research, for instance, there is already sufficient evidence to prove the brain responds to different degrees of CL, and that this can be elicited through exposure to stimuli, including grammatical and ungrammatical sentences (e.g., Canseco-Gonzalez, 2000; Yamada & Neville, 2007).

However, very few studies have investigated the effect of linguistic tasks on adults' CL using simple psychophysiological measures, such as HR, skin conductance, and pupil-area changes (Engonopulos, Sayeed, & Demberg, 2013). For example, Engonopulos et al. (2013) investigated the effect of linguistic complexity on CL in a dual-task scenario, measuring pupil-area and skin conductance. Their results found linguistic tasks induced higher CL based on the pupillometric measure.

Despite the proven success of experimental work investigating the effect of cognitive tasks on CL by measuring HR, none of this work has examined the carrying out of linguistic tasks by second-language (L2) learners. Thus, this current study seeks to start to fill this gap, by examining whether changes in HR could serve as an indicator of the CL associated with syntactic processing in sentence comprehension. The study hypothesises that ungrammatical sentences induce HR changes, and is based on the previous studies indicating that ungrammatical sentences induce CL according to an ERP measure.

The study's findings are expected to contribute to a better understanding of whether CL is susceptible to syntactic violations in sentences, so that teachers can become more aware of what factors induce CL in a classroom setting.

Research Question

Does the linguistic processing and comprehension of sentences with syntactic violations induce cognitive overload, resulting in significant fluctuations in HR?

Research Hypothesis

H0: There is no significant difference in the HR of an L2 subject when she is exposed to syntactic violations in sentences presumed to involve a higher cognitive load compared to well-formed sentences.

H1: There is a significant difference in the HR of an L2 subject when she is exposed to syntactic violations in sentences presumed to involve higher cognitive load compared to well-formed sentences.

Method

Independent and Dependent Variables (IV & DV)

The IV is the type of condition (grammatical and ungrammatical sentences), while the DV is the HR measure.

Subjects

An Indonesian younger adult (one woman, aged 33 years and 4 months, IELTS score: 6.5) was voluntarily recruited to participate in this experiment (see the appendix for information about the scales for International English Language Testing System (IELTS) scoring). An L2 learner typically has a slower linguistic processing speed (Ellis, 2009), and so this participant profile may yield more effective data (relative to a native speaker) regarding whether cognitive load is susceptible to syntactic processing. A native speaker of British English (n = 1) aged 27 years and 8 months was also recruited as a baseline for the purpose of comparison. Both subjects signed a consent form for participation.

Stimulus Material

The stimulus material in the present study was generated using 16 complex English sentences. Complex sentences contain an independent clause and a minimum of one dependent clause. A complex sentence was selected because it requires two clauses which makes the sentence longer, and consequently, the subject is unlikely to be able to process such sentences quickly.

The sentences (n = 16) were evenly divided into grammatical (n = 8) and ungrammatical (n = 8) sentences, all of which were semantically plausible. The ungrammatical sentences are similar to the grammatical ones, except that the subordinator position in each sentence is incorrect and the verb phrase (VP) position in each clause is incorrect, as shown in the table below:

Table 1

Ungrammatical Rule System

VP position	Example
The VP in the first clause is placed before the subject, while the VP in the second clause is placed at the end of the clause.	* Went to my son the gym he his all assignments did after.
The VP in the first clause is placed at the end of the clause, while the VP in the second clause is placed before the subject.	*Because I really the movie didn't like was the acting bad.

All the sentences (grammatical and ungrammatical) ranged from 10 to 12 syllables, and the words used were selected from the 2,000 most common words in the British National Corpus, to avoid any difficulties with semantic comprehension. The sentences were rated by another native speaker of English and L2 learner prior to the pilot study, to ensure that ungrammatical sentences would be sufficiently harder to comprehend than the grammatical ones.

Data Collection

The first step in the data collection process was to fit the subject with a Biopac monitor (Model MP36) with a sampling rate of 500 Hz to record her HR (The HR was calculated manually, so visual inspection and eyeballing may not be optimal due to human error). PsychoPy computer software (Version 1.85.4) was employed to control for stimulus presentation and response collection. The HR and responses were measured at an illuminated, quiet lab located in the School of Education, at University of Bristol. After the experimental protocol for the monitor was set up, the subject was seated in front of a computer. The subject was instructed to remain relaxed and not to talk during the recording. This was intended to minimise EMG artefacts and baseline drifts.

The task consisted of reading the two sets of sentences, which were randomly presented to the subject on the screen using a pure event-related design. The subject was not instructed prior to the experiment that some sentences were ungrammatical. Each sentence was presented individually to the subject to limit distracting or multiple stimuli. The subject was asked to read and comprehend each sentence and then instructed to press the spacebar to indicate she had finished and to move on to the next sentence.

The temporal interval (ISI) between the offset of one sentence and the onset of another was 8.5 seconds. This interval allowed the subject's HR to approach normal before reading the second sentence. Thus, a common baseline was obtained for all calculations (Cranford et al., 2014).

Results

The statistical analysis reveals that the average HR of the experimental subject in grammatical condition was 90.34 (*SD* = 3.03, *SE* = 1.07) out of a total of eight sentences, while the average HR in the ungrammatical condition was 89.98 (*SD* = 1.87, *SE* = .66, see Table 1 and Figure 1). An independent-samples t-test was conducted to compare the HR in grammatical and ungrammatical conditions. There was not a significant difference in the HR t (14) = -.28, p = .79.

The average HR of the control subject in the grammatical condition was 73.49 (*SD* = 4.23, *SE* = 1.49), while the average for the ungrammatical condition was 74.92 (*SD* = 5.10, *SE* = 1.80, see Table 1 and Figure 1). An independent-samples t-test was conducted to compare the HR in grammatical and ungrammatical conditions. There was not a significant difference in the HR t (14) = .608, p = .55.

Table 2

Mean HR (BPM) and SD in G and UNG for Both Subjects

Condition	Experimental		Control	
	M	*SD*	*M*	*SD*
G	90.34	3.03	73.49	4.23
UNG	89.98	1.87	74.92	5.10

Note. G = Grammatical; UNG = Ungrammatical.

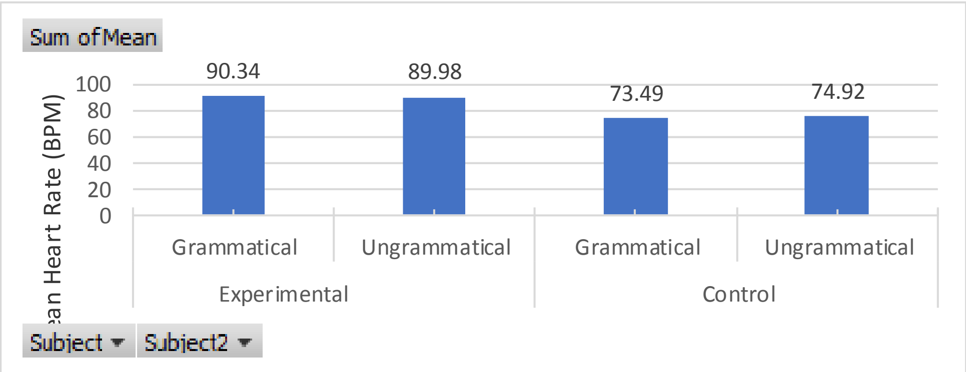

Figure 1. Mean HR comparisons in G and UNG for both subjects.

Descriptive statistics was also conducted for reaction time in both grammatical and ungrammatical conditions for both experimental and control subject. The average reaction time for the experimental subject in the grammatical condition was 2.05 (*SD* = .967), while the average for the ungrammatical condition was 12.00 (*SD* = .00). The average reaction time for the control subject in the grammatical condition was 2.55 (*SD* = .359), while the average for the ungrammatical condition was 5.53 (*SD* = 1.01, see Table 3).

Table 3

Mean (Seconds) and SD in G and UNG for Both Subjects

Condition	Experimental		Control	
	M	*SD*	*M*	*SD*
G	2.05	.967	2.55	.359
UNG	12.00	.00	5.53	1.01

Note. G = Grammatical; UNG = Ungrammatical.

Statistical Analysis was also conducted for the baseline data (i.e., the experimental subject was not exposed to any stimulus). An independent-samples t-test was conducted to compare the HR in the baseline and the ungrammatical condition. There was no a significant difference in the HR for the ungrammatical condition (*M* = 89.98, *SD* = 1.87) and the baseline (*M* = 89.83, *SD* = 1.73) *t* (14) = -.167, *p* = .87.

Discussion

The aim of the current project is to examine whether the linguistic processing that takes place during the comprehension of sentences with syntactic violations, presumed to involve a higher CL, induces significant fluctuations in HR. When analysing the results presented above for the experimental and control subject, the observed changes in HR for both subjects proved very similar under both grammatical and ungrammatical conditions. In other words, there was no pronounced increase in HR when both subjects were exposed to ungrammatical sentences. Thus, the null hypothesis, that there is no significant difference in the HR of an L2 subject upon exposure to ungrammatical sentences, failed to be rejected.

The present results are not in agreement with those stated in previously published studies, which employed cognitive tasks, such as stroops or chemical equations. This can be supported by the baseline data which was not significantly different from the ungrammatical condition. However, the results are not sufficient to conclude that the linguistic demands of the task cannot stimulate an increase in HR as a function of cognitive processing, rather they merely offer initial indications that HR is less susceptible to CL induced by linguistic demands than cognitive (e.g., chemical or mathematical) ones. Additionally, it is important to note here, that in this study, both subjects completed the two conditions without any time constraints. This varies from previous studies which found a relation between cognitive tasks and HR when a time pressure was present (see literature for more information).

The rule system that governs the word order of ungrammatical sentences appears robust enough to make them ambiguous and different from the grammatical sentences. This is supported by the difference in the average reaction time for the grammatical and ungrammatical conditions. Indeed, the average reaction time for the ungrammatical condition was much greater than for the grammatical condition. This demonstrates that the subject spent much longer pondering the syntactic context in which the words were embedded to understand the whole sentence.

A further point is that this study includes some potential sources of limitation which probably affected the results. First, the results cannot be generalised due to the use of a single-subject study design. Such a design also maximises the possibility of individual differences between the experimental and the control subject. This limitation can only be controlled by increasing the number of subjects, to create an experimental and a control group.

A second source of limitation arises from the absence of a time pressure under both conditions (see literature for more information). This could be addressed in future research by developing timed and untimed tasks, assigning subjects to timed and untimed conditions.

The third source of limitation is the relatively small number of stimuli grammatical sentences (n = 8) and ungrammatical sentences (n = 8) shown to the participants. However, this limitation is less significant than the limitations mentioned above. This is because eight stimuli in each condition are likely to have had a relatively lesser influence on the findings than the absence of time pressure. This limitation can be improved upon by increasing the number of sentences to which the subjects are exposed.

In summary, the study investigated the effect of syntactic violations in sentences on CL, as measured by HR. The literature suggests that cognitive load induces HR changes. However, the present study suggests that this effect cannot be induced by CL when the stimulus is grammatical versus ungrammatical sentences. However, due to experimental limitations, it is not possible to draw reliable conclusions to support either the experimental or the null hypothesis. Consequently, further research addressing the limitations mentioned above is required to verify the results.

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Appendices

Appendix A—Participant Consent Form

Consent Form

Full Title of Project: The Impact of Syntactic Processing in Sentence Comprehension on Cognitive Load Using the Measure of Heart Rate

		Please tick the Box
1	I confirm that I have read and understand the information sheet about the study and have had the opportunity to ask questions.	☐
2	I understand that I will participate voluntarily.	☐
3	I am free to withdraw at any time without giving a reason, and the data will be destroyed immediately in a secure manner.	☐
4	I agree to take part in the above study.	☐
5	I agree to the heart rate and the responses being recorded.	☐
6	I understand that all personal information and responses will remain confidential.	☐
7	I have received a copy of this Consent Form and the information sheet related to the project.	☐

______________________ ______________ ______________________

Name of Participant Date Signature

______________________ ______________ ______________________

Name of Researcher Date Signature

Appendix B—Grammatical and Ungrammatical Sentences

N	Sentence	Grammaticality	Subordinate
1	The dog went to the dining room after it smelled meat.	GR	after
2	My girlfriend changed her name after she left America.	GR	after
3	He didn't go to school because the weather was snowy.	GR	because
4	I didn't play basketball because I went home to study.	GR	because
5	My son didn't receive an "A" although he studied hard.	GR	although
6	Smith still makes mistakes although he is well trained.	GR	although
7	The girl felt so comfortable when she met her parents.	GR	when
8	John could imagine everything when he read the story.	GR	when
9	Went to my son the gym he his all assignments did after.	UNGR	after
10	After the big cat your milk drank came in it the kitchen.	UNGR	after
11	Heated I my pizza in the microwave it cold was because.	UNGR	because
12	Because I really the movie didn't like was the acting bad.	UNGR	because
13	Lisa the history exam passed was he very sick although.	UNGR	although
14	Although Ali his job continued to do had he an accident.	UNGR	although
15	Found John several attractions he Bristol went to when.	UNGR	when
16	When believed in my son horror stories he younger was.	UNGR	when

Appendix C—The IELTS 9-Band Scale

(Retrieved from https://takeielts.britishcouncil.org/find-out-about-results/understand-your-ielts-scores)

Band score	Skill level	Description
Band 9	Expert user	You have a full operational command of the language. Your use of English is appropriate, accurate and fluent, and you show complete understanding.
Band 8	Very good user	You have a fully operational command of the language with only occasional unsystematic inaccuracies and inappropriate usage. You may misunderstand some things in unfamiliar situations. You handle complex detailed argumentation well.
Band 7	Good user	You have an operational command of the language, though with occasional inaccuracies, inappropriate usage and misunderstandings in some situations. Generally you handle complex language well and understand detailed reasoning.
Band 6	Competent user	Generally you have an effective command of the language despite some inaccuracies, inappropriate usage and misunderstandings. You can use and understand fairly complex language, particularly in familiar situations.
Band 5	Modest user	You have a partial command of the language, and cope with overall meaning in most situations, although you are likely to make many mistakes. You should be able to handle basic communication in your own field.
Band 4	Limited user	Your basic competence is limited to familiar situations. You frequently show problems in understanding and expression. You are not able to use complex language.
Band 3	Extremely limited user	You convey and understand only general meaning in very familiar situations. There are frequent breakdowns in communication.
Band 2	Intermittent user	You have great difficulty understanding spoken and written English.
Band 1	Non-user	You have no ability to use the language except a few isolated words.
Band 0	Did not attempt the test	You did not answer the questions.