"Overloading" Cognitive (Work)Load: What Are We Really Measuring?

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Abstract. Cognitive load is one of the most studied constructs in NeuroIS [1]. Not surprisingly, we have identified 27 papers presented at NeuroIS retreats between 2012 and 2020 which included measurement of cognitive load or related constructs. This paper reviews terminology used to refer to cognitive load, mental workload and its variations, as well as their operationalizations and measurements. All 27 papers employed physiological NeuroIS measures, while six of them additionally used subjective self-ratings. The wide range of measurements prompts us to question if we are measuring the same construct. We provide an overview and a summary of cognitive load terminology and measurement used in these 27 papers and conclude with recommendations for future research.

Keywords: Cognitive load · Mental workload · Workload · Attentional load · Executive function load · Working memory · Information overload · Measurement

1 Introduction

Cognitive load is one of the most studied constructs in NeuroIS [1]. As the field develops and matures it is useful to review our conceptualizations, operationalizations and measurements of this important construct. This paper starts by reviewing papers published in NeuroIS Retreat between the years 2012 and 2020. The specific years are defined by the online availability of papers (and, in the earlier years, abstracts). We provide an overview of cognitive load terminology and measurements used in these 27 papers and conclude with recommendations for future research.

2 Background

Historically, cognitive load (CL), mental workload (MW) and memory load (mL) originated mostly independently from different fields, CL from Educational Psychology, MW from Human Factors and Ergonomics [2], and mL from cognitive psychology (e.g., [3]). The constructs are explicated by three theories prominent in their respective fields, CL by Cognitive Load Theory (CLT) [4], MW by Multiple Resource Theory (MRT) [5], mL by Baddley's theory of working memory (Wm) [6]. The constructs share core theoretical assumptions [7] and are similar in their assumption of limited mental capacity and

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competing task and environmental demands. The originating fields and many cognate disciplines continue to be interested in investigating this construct (and related). This continued trend is exemplified in a recently (2017) established series of International Symposia on Human Mental Workload (www.hworkload.org) [8]. In spite of the many decades long interest, the constructs and their measurement are still being disputed. For example, there is no common agreement on the three sub-constructs of CLT, the intrinsic, extraneous, and germane load and the new approaches to their measurement continued to be proposed [9]. As our review shows, the diversity of CL/MW/mL conceptualizations, operationalizations and measurements is also present in NeuroIS work which employed this construct (or shall we say these constructs?). In the text of this paper we will continue referring to it by Cognitive Load (CL).

Cognitive load measurement methods can be divided into 1) physiological (objective), 2) subjective, and 3) task performance measures. The physiological measures include signals from the central nervous systems (such as, brainwaves - EEG, oculography, pupillometry), and physiological signals from peripheral nervous system (such as heart rate variability - HRV, and electrodermal activity - EDA). The subjective measures rely on self-ratings scales (such as, NASA TLX, [40, 41]). The task performance measures include task completion time, number of errors, reaction times to secondary task. Another aspect of CL measurement is whether we measure instantaneous, average, accumulated, or peak load [41]. We review and classify NeuroIS Retreat papers using these types of measurements.

3 Method

We reviewed papers published at NeuroIS Retreat between 2012 and 2020. The papers were identified by performing search for "*load" (i.e. "load" with any prefix) on full-text of proceedings from 2012–2014 and on paper titles and abstracts from 2015–2020. The usage of "*load" was then manually checked. Only one paper was eliminated in this process, because it investigated a more general constructs of work overload and stress. We also searched for "mental effort" and did not identify any additional papers. The earliest identified work, was published as an abstract in NeuroIS Retreat 2012. To include measurements used in this research, we have identified a full conference paper where they were published [10]. In all other cases, we include information reported in the papers. We extracted from the papers all terms used to refer to some aspects of cognitive load, its descriptions, if any, as well as operationalizations and measures. In addition, whenever available we followed citations to the methods and measurement papers and reviewed them to include original terminology and further details of measurement described in these papers. Table 1 and Table 2 show a summary. Table 3 lists descriptions or definitions of cognitive load, if they were explicitly provided in the reviewed papers. Due to space limitations, we do not include all data extracted from the 27 papers.

Table 1. Summary of reviewed papers – part 1.

#	Year	Cit.	Paper type & N	Terms used	Subj. m.	NeuroIS measurements	Constructs in cited papers
1	2012	[11]	N=17, N=24. abs.	CL	Cam.	EEG: B-Alert workload index. Absolute/relative power spectra in 1-40Hz bands.	IO
2	2014	[12]	N=12	MW		Pupillary hippus (unrest)	MA
3	2015	[13]	N=13	MW		Absolute mean pupil diameter	
4	2015	[14]	WiP, pilot, N=2	CL;CW		Z-scores of pupil dilation. Mean of Z-scores per task.	CL (listening)
5	2015	[15]	WIP	CL	NASA	pupillometry and heart rate variability	
6	2015	[16]	WiP	CL		pupillometry, EEG	CW; WmL;ME
7	2015	[17]	WiP, pilot N=3	CL		Absolute pupil diameter	CL
8	2016	[18]	WIP	CL;ML		EEG "activations"; not specified further	
9	2016	[19]	N=45 see 2015 WiP	MW	NASA TLX	Absolute mean pupil diameter	Creation & retrieval of memories
10	2016	[20]	N=156	CW		EEG. spectral power ratio - engagement index	M engagement in automated task
11	2016	[21]	N=12; pilot	IO		EEG: Mindwave Neurosky headband + Neuro Experiment software output	
12	2016	[22]	N=10	MW; CL;CW	Cam.	EEG: Instantaneous, average, accumulated and peak load calculated from eXecutive Load Index (XLI) = ((delta + theta)/alpha) power ratio 2s compared with previous 20s.	CL
13	2017	[23]	N=12	MW		Stationary of absolute pupil size	Pupil response - Cognitive effects; Eye liveness
14	2017	[24]	N=22	CL;CW		Pupil diameter and square of pupil diameter. Most likely calculated from mean absolute pupil diameter per task (question)	MW
15	2017	[25]	WiP	CL; CO		no further detail	
16	2017	[26]	N=23	CL		Absolute mean pupil diameter	MA; CL
17	2017	[27]	WiP	CL		Pupial dilation to obtain continuous, average, and accumulated load. not specified in further detail	CL

Year-NeuroIS year (not pub. year); Cit.-citation to a paper in the list of references; N-number of participants; WiP-Work-in-Progress (otherwise completed research); Cam.-Cameron 6-item Likert scale; NASA-NASA TLX scale; CL-Cognitive Load; CW-Cognitive Workload; CO-Cognitive Overload; M-Mental; MW-Mental Workload; ME-Mental Effort; MA-Mental Activity m-memory; mL-memory Load; WmL-Working memory Load; IO-

Table 2. Summary of reviewed papers – part 2.

#	Year	Cit.	Paper type & N	Terms used	Subj. m.	NeuroIS measurements	Constructs in cited papers
18	2018	[28]	WiP; N=12	AL;AO; CL;ME;IL		Pupil dilation. EEG: event-related desynchronization in alpha band. not specified in further detail	WmL
19	2018	[29]	N=118; N=60;	CL; IO		Battery of eye-tracking derived measures: Fixation duration and count; Saccade duration and count; Pupil dilation - from baseline; pupil diameter diff; Eye blinks: count and duration. Establishes some reliability of these measures.	CL
20	2019	[30]	WiP	CL		pupil dilation	CL
21	2019	[31]	WiP (planned N=65)	CL;EFL		Three types of CL = three types of EFL 1. CL on inhibition: alpha event-related synchronization; 2. CL on updating: theta power; 3. CL on shifting: amplitude of posterior switch positivity (parietal electrodes)	WmL; m inhibition & updating; Attention shifting
22	2020	[32]	WiP	CL	NASA	Pupil dilation; EEG: theta, alpha and beta powers; No specific detail	M activity
23	2020	[33]	N=17	CL;CPL		Pupil: mean pupil diameter relative to mean pupil overall; EEG. relative low theta band power (10s post/10s pre)	Cognitive load
24	2020	[34]	N=10	CL		EEG. spectral power ratio (Beta/(Alpha + Theta)) - engagement index	M engagement in automated task
25	2020	[35]	N=10	CL		EEG: accumulated, average, peak load calculated from theta/beta power ratio; Neural signal complexity: fractal dim, multi-scale entropy, detrended fluctuation analysis.	Mind-wandering; CL during continuous cognitive task performance
26	2020	[36]	N=20	IO; CL; W	NASA	Electrodermal activity (EDA); Task completion time	CL
27	2020	[37]	N=60, prelim. results N=6	CL		EEG. spectral power ratio (Beta/(Alpha + Theta)) - engagement index	M. engagement in automated task

Year-NeuroIS year (not pub. year); Cit.-citation to a paper in the list of references; N-number of participants; WiP-Work-in-Progress (otherwise completed research); Cam.-Cameron 6-item Likert scale; NASA-NASA TLX scale; AL-Attentional Load; AO-Attentional Overload; CL-Cognitive Load; CW-Cognitive Workload; CO-Cognitive Overload; M-Mental; MW-Mental Workload; ME-Mental Effort; MA-Mental Activity m-memory; mL-memory Load; WmL-Working memory Load; IL-Information Load; IO-Information Overload; EFL-Executive Function Load.
Note, we provide citations to all cited papers on cognitive load measurement at the end of this paper's reference list.

Table 3. Cognitive Load descriptions provided in reviewed papers.

#	Year	Cit.	Terms used	Description or definition of Cognitive Load
5	2015	[15]	CL	"CL characterizes the demands of tasks imposed on the limited information processing capacity of the brain in the same way that physical workload characterizes the energy demands upon muscles. CL therefore represents an individual measure considering the individual amount of available resources and task-specific factors imposing CL. As independent construct, CL predicts performance for task execution, since high CL leads to poor task-performance and to wrong decisions"
7	2015	[17]	CL	"Cognitive load characterizes the demands of tasks imposed on the limited information processing capacity of the brain and constitutes an individual measure considering the individual amount of available resources"
8	2016	[18]	CL;ML	CLT. "Limited working memory with partly independent processing units for visual/spatial and auditory/verbal information, which interacts with a comparatively unlimited long-term memory"
12	2016	[22]	MW; CL;CW	"Mental workload can be defined as "the set of mental resources that people use to encode, activate, store, and manipulate information while they perform a cognitive task"
18	2018	[28]	AL;AO; CL;ME;IL	CLT "Cognitive load is the mental effort exerted by an individual to solve a problem or accomplish a task, during which information is retrieved from long term memory and temporarily stored in working memory for processing"
19	2018	[29]	CL; IO	CLT. Def: "the amount of working memory resources required in cognitive task execution"
20	2019	[30]	CL	"theoretical foundation grounded in the feature integration theory, dual processing, cognitive fit, cognitive load theory and works by Tversky and Kahneman"
21	2019	[31]	CL;EFL	Cognitive load as a mediator: between interruption characteristics and performance. Executive Function load. Cognitive load on inhibition; on updating; on shifting executive function (EF).
25	2020	[35]	CL	Cognitive load refers to the amount of working memory resources required to perform a particular task

Paper numbers (#) are from Table 1 and Table2.
Year-NeuroIS year (not pub. year); Cit.-citation to a paper in the list of references;
CL-Cognitive Load; CW-Cognitive Workload; CO-Cognitive Overload; M-Mental; MW-Mental Workload; ME-Mental Effort; MA-Mental Activity m-memory; mL-memory Load; WmL-Working memory Load; IO-Information Overload;

4 Observations

We observe a wide range of terminology used across papers. Eleven papers used CL, while four papers used MW. The remaining twelve papers used different terms interchangeably, presumably to refer to the same construct. For example, paper #12 [22] referred to MW, CL and CW. #18 [28] referred attentional load (AL), attentional overload (AO), CL, mental effort (ME), as well as to information load (IL). #19 [29] referred to CL and information overload (IO), while #21 [31] referred to CL and executive function load (EFL). We also observe differences in terminology between NeuroIS Retreat papers and cited by them papers which were used to inform measures and variables. For example, #9 [19] cites paper on a measure (pupil dilation) which reflects creation and retrieval of memories, but uses it to assess MW. Paper #25 [35] cites measures of mind-wandering and, separately, CL on continuous task performance and uses them to assess CL.

In Table 3 we provide a list of descriptions or definitions of CL, whenever they were provided in reviewed papers (#5, #7, #8, #12, #18, #19, #20, #21, #25). In addition, we observe that in six more papers (#14, #15, #16, #22, #26) Cognitive Load Theory provided an implicit definition of CL. A few papers (#8, #18, #25) refer in their definitions explicitly to working memory resources or to its limited capacity. Two describe mental demands imposed by a task (#5, #7) (which would roughly correspond to intrinsic load in CLT), while one (#18) refer to "mental effort exerted by an individual". We think that mental effort, while strongly related to CL, is a different construct and should not be equated with CL (e.g., see [38] for a recent review).

Six papers used a subjective measure using either Cameron self-reported 6-item Likert scale [39] and NASA TLX [40, 41]. All 27 papers used one or more NeuroIS physiological measures. In that nine papers used only EEG, ten used only pupil dilation, four pupil and EEG, one pupil and HRV, one a battery of eye-tracking measures (including pupil), one electrodermal activity & task completion time, and one did not specify any. As the NeuroIS field progresses, we observe measurements of more nuanced aspects of cognitive load. For example, papers #12, #17, #25 [22, 27, 35] introduce instantaneous, average, accumulated, and peak load [42]. A few earlier projects used absolute values of pupil dilation. Since this measure suffers from many drawbacks (sensitivity to external lightening and foreshortening errors), other projects used somewhat more advanced measures such as relative pupil dilation (or normalized Z-scores) or stationarity of pupil dilation signal. A few EEG spectral power ratios were used. One `((delta+ theta)/alpha)` measures executive load (XLI [43]), and thus is closely related to CL, while another `(beta/(alpha+ teta))` measures engagement [44] and thus shouldn't be simply equated with CL.

5 Comments and Recommendations

The wide variety of terms and measures used is somewhat concerning. Certainly, researchers may be interested in different constructs and sub-constructs related to CL, but they should be very explicit about what is being measured and avoid referring to general constructs like CL, while a more narrowly defined aspect is being measured. CL measures derived from the central (EEG, oculography) vs. peripheral nervous system (HRV, EDA) potentially tap into different aspects of CL.

Based on our review we offer the following recommendations:

- Terminology
  - Explicitly define constructs and how their measurement is operationalized.
  - Use terminology carefully and avoid referring to the same construct by different terms.
- Measurement
  - There is a wide variety of measurements used therefore it is difficult to offer a short list of specific recommendations. What follows are general guidelines.
  - Be explicit in defining a segment of time (or a unit of interaction) over which measures are aggregated (e.g., a task, a screen).
  - For *eye-tracking measures* - follow systematic approaches, such as [46, 47]. One of the reviewed papers [29] presented at NeuroIS'2018 provided initial demonstration of reliability of a battery of eye-tracking measures.
  - For *pupil-derived measurement* – use relative measures within subjects normalized to some baseline; incorporate lightning conditions or use measures not affected by lightning conditions; be aware of foreshortening errors. One possibility is to consider the Index of Pupillary Activity [48], a measure based on detecting frequency of periodic fluctuations of pupil diameter. It's insensitive to the lightning conditions and foreshortening errors, and offers a freely available algorithm.
  - For *EEG spectral power ratios* – there is a variation of employed measures. It is certainly warranted by measurement of different sub-constructs related to CL. However, let's consider other well established measures in assessing CL, such as alpha/theta ERD/ERS [49].
- Consider investigating reliability, validity and sensitivity of measures which we are used to assess CL. Recent examples of such work in NeuroIS Retreat include [29] and in other communities include for example [50, 51].

CL has been long of interest to many fields concerned with human performance. It is a complex construct and we still face difficulties in defining it, in understanding which factors influence it, and in measuring it. Such difficulties are not limited to NeuroIS, other cognate communities face them as well [9, 38, 45].

6 Limitations and Future Work

One limitation of our review is equal treatment of work-in-progress (WiP) and completed-research (CR) papers. The WiP papers report on research plans or pilot results. Consequently, the concepts and methods presented in them may not be fully developed yet, thus applying to them the same level of scrutiny as to the papers reporting on CR may be unjust. Furthermore, a few authors publish in NeuroIS Retreat sequential updates on their research projects. We have not attempted to group such papers, thus our summary may include "double counting".

This preliminary review was by design limited to NeuroIS Retreat, we plan to develop it in a more comprehensive (possibly systematic) review which includes publications from other conferences and journals. CL is just one of many constructs investigated in NeuroIS [52], we should consider other topics and constructs.

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