Mechanism, measurement, and quantification of stress in decision process: a model based systematic-review protocol

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Abstract

Background: Every human action begins with decision-making. Stress is a significant source of biases that can influence human decision-making. In order to understand the relationship between stress and decision-making, stress quantification is fundamental. Different methods of measuring and quantifying stress in decision-making have been described in the literature while an up-to-date systematic review of the existing methods is lacking. Moreover, mental stress, mental effort, cognitive workload, and workload are often used interchangeably but should be distinguished to enable in-depth investigations of decision-mechanisms. Our objectives are to clarify stress related concepts and review the measurement, quantification, and application of stress during decision making activities.

Methods: We developed and followed a systematic reviews protocol to analyze the literature related to stress in decision-making. We systematically searched Web of Science, Scopus, PubMed, and ERIC (EBSCO) between 1990 and 2020 with English language. We will include any literature reporting measurable stress-related outcomes, including stress, workload, cognitive workload, mental effort during the decision-making process. All research designs investigating the quantification and measurement of stress for healthy adults are eligible for this review. Research postulates are proposed based on the stress-effort model. Two reviewers will independently screen the articles for inclusion and assess for study quality using the Quality Assessment of Diagnostic Accuracy Studies-2 tool. We will extract data from each study including research objective, research method, research domain, triggering method, objective measure, subjective measure, and research results for knowledge syntheses.

Discussion: The physiological responses to stress are proposed for verification. This systematic review will provide knowledge on decision mechanisms under stress and stress related concepts. The improved understanding on stress measurement, quantification, and application in specific research context will advance methods to study and optimize decision making.

Keywords: systematic review; protocol, stress; acute stress; workload; cognitive workload; mental effort; stress measures; stress quantification

Background

Every human action begins with decision-making, which is an established discipline that identifies and selects alternatives based on the values and preferences of decision-makers [1]. Decision-making can be characterized as the organism’s ability to choose the most adaptive action and outcomes from all possible alternatives [2].
Stress is a significant source of biases and can influence human decision-making [3, 4, 5]. Stress can be defined as 'the nonspecific result of any demand upon the body' [6]. This definition indicates that stressor, as the load or stimulus, triggers stress response [7]. A stressor can be a physical trigger that threatens homeostasis [8, 9, 10], such as injury, noise, and extreme temperature. A stressor can also be a psychological trigger, such as time-pressured tasks, trauma events [11], and unexpected events. The stress response represents the body’s attempt to counteract the stressor and re-establish homeostasis [8], such as increased blood pressure, the increased cortisol levels, and the decreased heart rate variability. Hence, these physiological responses can be proxy measures for stress. The entire process, from the stimulus activation to the individual response, is a decision-making process. Stress can bias decision-making strategies, affecting the individual decision-making ability to perform actions, and may cause mistakes and incorrect decisions [12, 13].

Different levels of stress have different impacts on decision-making. Stress can be classified into "eustress" (positive stress) and "distress" (negative stress) [14]. Eustress is considered as constructive stress because it will not cause any issues in solving and pursuing goals. In contrast, it can stimulate the individual to feel happy or motivated, which improves productivity and performance. On the contrary, distress is considered as destructive stress because it is more challenging than eustress to deal with and can become a source of barriers to achieving goals [15]. Distress can damage cognitive abilities and reduce individual performance. The Yerkes-Dodson law illustrates the relationship between stress and performance in an inverse U-shaped curve [16]. However, the Yerkes-Dodson law did not specify factors that influence stress. Furthermore, for simple problems, people can perform excellently with minimal stress. Nguyen and Zeng thus revised the Yerkes-Dodson law and proposed the stress-effort model [17], as shown in Figure 1. Given that both the presence and the level of stress could influence decision-making, it is critical to measure and quantify stress.

Likewise, the stress-effort model shows a bell-shaped curve relationship between stress and effort. The effort may enhance with stress, up to a point, then it will decline with continuously increased stress. Nguyen and Zeng also developed a conceptual stress equation to describe the relationship of stress with the perceived

![Figure 1 The stress-effort model. Source: Nguyen and Zeng [17]](image)
workload, knowledge, skills, and affect [18], as shown in a mathematical form below:

\[
\sigma = \frac{w_p}{(k + S)} \ast \alpha
\]  

(1)

where \(\sigma\) represents stress, and \(w_p, k, S,\) and \(\alpha\) represents perceived workload, knowledge, skills, and affect, respectively.

To measure stress is to measure the stress perceived by individuals [19]. Researchers measures the difference from stressful situation to the normal situation (baseline) of individuals. The process of stress activation and the process of stress recovery can make this difference. Moreover, how quickly people recover from the episode of stress can determine whether it is acute stress (short-term stress) or chronic stress (long-term stress) [20, 21]. Acute stress will develop rapidly and last for a short time through a particularly stressful event. Chronic stress can bring depression, personality disorders, and diseases [22, 23, 24]. Our review will focus on acute stress, which has been the central focus of decision-making [25].

It can be seen from Equation 1 that stress is related to workload, knowledge, emotion, perception, cognitive and affective capabilities. Previous research on the relationship between stress and decision-making had involved concepts, such as mental effort, workload, cognitive workload [26, 27, 28, 29, 30, 31]. These stress-related concepts sometimes are used interchangeably to describe the same phenomenon [32, 33] and sometimes the same concept had been used to refer to different phenomena [34, 35]. Correctly distinguishing these concepts can improve the interpretations of findings from stress-related experiments or applications. Therefore, this review will integrate these stress-related concepts to elucidate accurate stress measurement and quantification through a decision-making mechanism.

Stress measures can be categorized into subjective and objective measures. Subjective measures assess stress using self-report protocols or questionnaires [1, 2, 3, 4, 36, 37]. In contrast, objective measures use devices to assess physiological, physical, or behavioural responses [38, 39, 40, 41]. Both measures have their unique advantages and disadvantages. Subjective measures are perceived to have high reliability and user trust [42]. However, as self-report are retrospective measures, subjective measures can induce recall bias [19], which may cause errors and biases that could compromise their validity. Meanwhile, objective measures could have high validity [42]. Taking advantage of the rapid development of sensor technologies and data science, objective measures have become increasingly popular in recent years [17, 38, 43, 44]. While the adoption of objective measures brings significant benefits to stress measurement and quantification, advanced interdisciplinary knowledge is critical to their successful applications. Furthermore, both subjective and objective measures are combined to achieve a comprehensive stress assessment [17, 45]. Therefore, this review will summarize the experiment protocols of stress measures, categorizes measures according to their functions and applications, and survey and assess the stress quantification algorithms and processing methods.
**Methods**

**Research postulates**

The foundation of this review comes from the stress-effort model shown in Figure 1 [17]. Herein, we propose a general decision mechanism, (as shown in Figure 2), which to integrates stress and stress-related concepts into the stress-effort model.

The general decision mechanism consists of three components specified below:

- **Input**: The input of the decision mechanism is a stressor.
- **Process**: The decision-making process involves four distinctive stages, including high-level cognitive activities [46] such as: “perception and engagement”, “understanding”, “analysis”, and “decision making”.
- **Output**: The output consists of everything produced by the decision-making process, such as behaviours, stress, and cognitive workload [47].

A stressor, as the input, stimulates an individual to start the decision-making process. Guided by the individual’s knowledge, skills, and affect, each stage of the decision-making process leads to certain behaviours while taking corresponding mental effort and triggering consequential mental stress [47]. In Figure 2, behaviours contains physical actions associated with individual psychomotor skills and abilities [48]. In addition, a cognitive workload will be created and becomes the input for the next stage. As the process continues to evolve, cognitive workload, stress, and behaviour are recursively updated.

While decision-making can be a controlled, rational, and effortful process, it can also be automatic, unconscious, emotional, and effortless. During the rational decision-making process, people can reason with their knowledge and skills to deal with their cognitive workload. In contrast, automatic decision-making has no self-awareness or control of the mind [49]. The former occurs when the cognitive workload is mild, whereas the latter kicks in when the stress levels are excessively
heavy or lacking [18]. Figure 2 describes the rational decision-making process, and Figure 3 illustrates the emotional (automatic) process of decision-making.

![Figure 3 Automatic decision mechanism under extreme stresses](image)

Like the rational decision-making mechanism shown in Figure 2, the automatic decision-making mechanism also includes three components: input, process, and output but with only two stages, which are “perception and engagement” and “decision making”. Thus, people would make their decisions based only on perception and engagement while skipping the understanding and analysis stages.

Several physiological responses to stress are involved during decision-making. A stressor will stimulate many organisms and various systems in the human body, including the automatic nervous system (ANS), the hypothalamic-pituitary-adrenal axis (HPA axis), and the brain network [9]. Figure 4 illustrates the physiological responses to stress, which serves as the foundation for stress measurements.

![Figure 4 The physiological responses to stress](image)

ANS contains the sympathetic nervous system and the parasympathetic nervous system. Stressor stimulates the sympathetic nervous system and modulates control...
on the Adrenal medulla, which creates the synthesis and secretion of norepinephrine and epinephrine. The ANS triggers physiological responses, such as heart rate, HRV, blood pressure, eye movements, and skin conductance.

Stress can also induce an increased cortisol output via the HPA axis activation. When the stressor is applied to the HPA axis, the hypothalamus creates corticotropin-releasing factor (CRF), stimulating the pituitary. Then the pituitary secretes adrenocorticotropic hormone (ACTH), which stimulates the adrenal. The adrenal cortex is stimulated and secretes glucocorticoid (GC), which signals negative feedback to CRF and ACTH. Cortisol is the most critical human glucocorticoid, which is known as the stress hormone. It elevates blood sugar levels, enhances the brain’s use of glucose under stress conditions.

Research over the past years has clarified that the brain network related to stress is involved in responding to stressors. With brain imaging technology development in mammals and the remarkable progress in genetic studies, the understanding of stress networks is rapidly growing in recent years. Stress networks are a set of highly connected brain structures that are activated when the animals perceive their surroundings or are exposed to various stressful events [50]. The brain network as shown in Figure 4 indicates EEG and brain region activation under stress.

Meanwhile, the body and nervous system’s organization and interactions reflect a high degree of complexity and multidirectional communication. Although stress involves many factors and various systems of the body, a stress reaction is a significant activation of stress response systems that result in a cascade of neuroendocrine changes [50]. Stress and related concepts, such as mental effort, workload, and cognitive workload, can be monitored and measured using physiological responses. Several physiological responses can be used as measurement metrics for stress, such as HRV, EEG, and NASA-TLX. Given the availability of multiple measurement methods, interests are increasing to identify the best methods and algorithms to measure and quantify stress. Researchers proposed a number of different measures. However, how to select the appropriate measures and metrics to measure and quantify stress remains a challenge.

Therefore, the literature review is based on the following four research postulates of stress in decision making:

1) there is Bell-shaped relationship between stress and effort;
2) stress is proportional to perceived workload, and inversely proportional to knowledge, skills, and affect;
3) there are two decision mechanisms: one is rational while the other is automatic. Both decision mechanism starts with a stressor as the input and ends with the output containing behaviours, stress, and cognitive workload. The output will recursively influence the decision process; and
4) responses in the automatic nervous system (ANS), the hypothalamic-pituitary-adrenal axis (HPA axis), and the brain network can be used to measure stresses during a decision process.

Protocol registration and reporting
The systematic review will identify available measures for measuring stress, and evaluate and summarize the quantification algorithms and processing methods of
different measures. This review will be conducted following the systematic review methodology and guideline by Normadhi, et al. [51]. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework will be used to guide the formulation of this systematic review protocol (see Additional file 1) [52]. The completed PRISMA-P checklist is provided in Additional file 2.

**Inclusion criteria**

**Population**
We will identify studies investigating the effect of acute stress in disease-free adults. We will exclude experiments conducted among pediatrics participants or population with illness or pregnancies.

**Outcomes**
The outcome of interest in this review is to explore the measurement, quantification, and application of emotional and rational decision process. This review focuses on studies investigating the theoretical or conceptual background of stress-related concepts. It also focuses on studies investigating the psychological measurement properties of stress-related concepts.

**Type of studies**
We will select studies published in peer-reviewed scientific journals and related conferences. Studies need to present empirical data and assessed acute stress. The language restriction will be enforced on the condition that the English abstract is provided. Moreover, studies that reported bio-signal measures with sufficient quality will be included.

**Information sources and search strategy**
We will conduct comprehensive literature search in the following databases:
- Web of Science, 1990-2020
- Scopus, 1990-2020
- PubMed, 1990-2020
- ERIC (EBSCO), 1990-2020

Search terms related to stress, stress-related concepts, stress measurements, stress quantification, and stress application will be used. Searching uses a combination of keywords from different search terms. The search strategy is detailed in Additional file 3. We use the topic (including title, abstract, and keywords) search in the search design to retrieve the results. This method is used to extract the most relevant research and reduce the number of articles that do not match the search. When the topic results are insufficient, other search structures (for example, title and abstract search) are performed.

**Screening and selection procedure**
Two reviewers will screen titles, abstracts, and keywords independently. Conflicts will be resolved through discussion. A third reviewer will resolve any conflicts through consensus. The full text of all remaining articles will be obtained and assessed independently for inclusion by two reviewers. Discrepancies will be resolved by discussion, and any disagreement will be evaluated by a third reviewer. Articles selected for inclusion in the review must meet the predefined inclusion criteria.
Data extraction and synthesis
For each included article, two reviewers will independently extract the data and verify the extracted data. If there is more than one publication reporting data from the same study, the first publication will be chosen to avoid double reporting data on the same participants. Two reviewers will also make a summary assessment of study validity and verify the assessment of validity. Any discrepancies will be resolved by discussion.

Data on the following factors will be extracted for each study: research objective, research method, research domain, triggering method, objective measure, subjective measure, and research results; the identification techniques and data analysis techniques. A standard information form to extract data from the selected articles [51]. Reviewers will use Mendeley to extract the essential information (e.g., title, authors, date of publication). Specific data will be extracted from each article based on the initial study categorization. Excel spreadsheet will be created and finalized after the two reviewers reviewed the data extraction. Reviewers will check the consistency of the information extracted from each article to achieve high-quality data extraction. Data extracted from the included articles will be synthesized separately for stress measurement and quantification. The application, i.e., the research domain and research question, of stress will also be summarized.

Quality assessment
The methodological quality of each included study will be assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool [53]. The QUADAS-2 is used to assess the risk of bias and applicability concerns in the study. Each study will be assessed from 4 domains: participant/measure selection, index test, reference standard, and flow and timing [54]. Classification of studies as low risk and high risk of bias and applicability will be based on these four domains. Studies with missing information for any of the domains were classified as having an unclear risk of bias or applicability for that specific domain. Other quality assessment tools will also be considered depending on the nature of final included studies.

Discussion
Our systematic review aims to synthesize previous evidence on the definition of stress, and the measurement, quantification, and application of stress. We propose that human effort in decision-making is related to individual stress through a Bell-shaped curve. The decision mechanisms present that decision making is a dynamic process under stress. According to the stress level, the decision process can be classified into rational and automatic processes. We also aim to map the physiological responses to stress during the decision process to guide the identification of stress measures.

To the best of our knowledge, this will be the first systematic review to investigate measures for stress and all stress-related concepts. Performing an inclusive search in significant databases across a 30-year timescale will cover related research studies on this topic. We have provided a comprehensive overview of stress and stress-related concepts, decision mechanisms and the physiological responses to stress in
Based on the relationship among stress and stress-related concepts, the decision mechanisms during rational and automatic decision processes are provided. The systematic review will focus on investigating the measurement, quantification, and application of stress and stress-related concepts, including workload, cognitive workload, and mental effort. This review will aid technicians and researchers in selecting suitable stress measures for specific purpose. More importantly, appropriate stress measure selection will improve experiment objectivity, which will positive affect stress quantification. Clearly, there is a wide range of stressors and stress responses. We seek to identify the effective methods to measure and quantify stress and stress-related concepts, which will provide technical support and theoretical foundation for stress-related applications. Moreover, we will identify research trends from the current literature, which aims to establish a solid base for stress measurement and quantification and to guide further research. We expect our results to have significant implications in research and practice under stress such as ergonomics, human-computer interactions, design, learning and training, and so forth.

### Competing interests
The authors declare that they have no competing interests.

### Abbreviations
EEG: Electroencephalogram; HRV: Heart rate variability; NASA-TLX: NASA Task Load Index; DOI: Digital Object Identifier; URL: Uniform Resource Locator; ANS: Automatic nervous system; SNS: Sympathetic nervous system; PNS: Parasympathetic nervous system; HPA: Hypothalamic–pituitary–adrenal; CRF: Corticotrophin-releasing factor; ACTH: Adrenocorticotropic hormone; GC: Glucocorticoid; PRISMA-P: Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocol; QUADAS-2: Quality Assessment of Diagnostic Accuracy Studies-2.

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### Author’s contributions
CS: manuscript writing. LY: critical revision of the manuscript for crucial conceptual improvement. XL: draft the manuscript and participate in early research. YZ: supervised research, design and develop the research framework, critical revision of the manuscript. All authors read and approved the final manuscript.

### Author’s information
YZ has published substantially in design and stress. Specific topics of his research include the science of design, methodology for innovative and creative design, and neurocognitive model of design creativity. His academic program at Concordia University, Canada, focused on design and stress, which has led to the stress-effort model and its applications to multiple applications to design, learning, education, management, and health. CS is a doctoral student working on quantification of stress. LY is an epidemiologist, whose research program focuses on biological mechanisms between human movement and health, behavioural clinical trials, and implementation science. XL focuses on the neural signal processing.

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Additional Files
Additional file 1 — PRISMA-P flow (DOCX 24 kb)
Additional file 2 — PRISMA-P checklist (DOCX 89 kb)
Additional file 3 — Search Strategy (DOCX 21 kb)
The PRISMA flow diagram for the systematic review

- Database records identified through database searching (n = )
- Additional research defined through other sources (n = )
- Records after duplicates removed (n = )
- Records screened by topic for relevancy (n = )
- Full-text articles assessed for eligibility (n = )
- Articles excluded (n = )
- Articles excluded (n = )
- Studies included in qualitative synthesis (n = )
### PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

| Section and topic | Item No | Checklist item | Information reported |
|-------------------|---------|----------------|----------------------|
| **ADMINISTRATIVE INFORMATION** | | | |  
| Title: | 1a | Identify the report as a protocol of a systematic review | |  
| Identification | | | |  
| Update | 1b | If the protocol is for an update of a previous systematic review, identify as such | |  
| Registration | 2 | If registered, provide the name of the registry (such as PROSPERO) and registration number | ✚ |  
| Authors: | | | |  
| Contact | 3a | Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author | ✚ |  
| Contributions | 3b | Describe contributions of protocol authors and identify the guarantor of the protocol | ✚ |  
| Amendments | 4 | If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments | ✚ |  
| Support: | | | |  
| Sources | 5a | Indicate sources of financial or other support for the review | ✚ |  
| Sponsor | 5b | Provide name of the review funder and/or sponsor | ✚ |  
| Role of sponsor or funder | 5c | Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol | ✚ |  
| **INTRODUCTION** | | | |  
| Rationale | 6 | Describe the rationale for the review in the context of what is already known | ✚ |  
| Objectives | 7 | Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO) | ✚ |  
| **METHODS** | | | |  
| Eligibility criteria | 8 | Specify study characteristics (such as study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review | ✚ |  
| Information sources | 9 | Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage | ✚ |
Search strategy

We will set no search limits on study design and type of intervention. The search strategy will focus on four key elements: definition (for example, psychological stress, workload), measurement (for example, EEG, HRV), quantification (for example, quantify, algorithm), and application (for example, training, driving). The definition of stress and its related concepts will be searched from significant articles and research. Considering the published time of these articles, regarding the definition of stress and stress-related concepts, may earlier than the searching range we original planned, the definition part will not be systematically reviewed. By considering the combination of measurement and quantification in stress experiment, the measurement and quantification of stress and its related concepts will be searched together. Then, we will search the application of stress and its related concepts.

| Search terms       | Keywords                                                                                                                                 |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Measurement and quantification | (“mental stress” OR “acute stress” OR “psychological stress” OR “workload” OR “cognitive workload” OR “cognitive engagement” OR “affect” OR “fatigue”) AND (EEG OR electroencephalogram OR “heart rate variability” OR HRV OR cortisol OR “electrodermal activity” OR EDA OR “galvanic skin response” OR “electrodermal assessment” OR “facial expression” OR “face reader” OR “facial expression analysis” OR “eye tracking” OR “NASA TLX” OR “NASA task load index”) OR (device OR protocol OR measurement OR experiment OR test OR measure OR equipment) OR (quantification OR quantify OR algorithm) AND (application OR design OR learning OR training OR driving OR HCI OR “human-computer interaction” OR ergonomics) |
2. Application  
(application OR design OR learning OR training OR driving OR HCI OR “human-computer interaction” OR ergonomics)

3. Publication time limit  
Time range: 1990-2020

4. Participants  
Limit: Adults 19+ years

Searches combined with AND: 1 AND 2 AND 3 AND 4.

Table 1 lists the search strategy. Subsequently, the Boolean operator "OR" will be merged to include synonyms and alternate spellings, and then the Boolean operator "AND" will be used to link the keywords and create the final search string.

References
[1] B. Kitchenham and S. Charters, Guidelines for performing Systematic Literature Reviews in Software Engineering, 2007.