Designing meaningful interaction with mental workload data

A Master Graduation Thesis by

Yu-Wei Chen

TU Delft, March 2024

Designing meaningful interaction with mental workload data

A Master Graduation Thesis by

Yu-Wei Chen

March 2024

Author

Yu-Wei Chen

MSc. Design for Interaction

Faculty of Industrial Design Engineering (IDE)

Delft University of Technology

Supervisory team

Chair

Dr. Christina Schneegass
Assistant Professor
Department of Human-Centered Design (HCD)

Mentor

Dr. Tilman Dingler
Associate Professor
Department of Sustainable Design (SDE)

TU Delft

Acknowledgements

First and foremost, I would like to express my gratitude to my two supervisors, Christina and Tilman. Both of them have granted me immense freedom in exploration, and provided substantial support in both topic discussions and administrative procedures. They have met with me almost every week, guiding me step by step. I know I have a lot of shortcomings, and it is the tolerance and extensive help from both teachers along the way that I cannot express my gratitude enough for.

Furthermore, I would like to extend my thanks to all participants involved in this thesis, numbering more than thirty individuals. Among them, special appreciation goes to Yin, Sophia, and Lori, who discussed issues with me and provided invaluable advice when I was under uncertainty. The topic of this thesis pushed me far beyond my comfort zone. While I am honored to explore such a new research field, the process was mostly filled with self-doubt and uncertainty. It was through the interviews and experiments with the participants that I gradually found direction. Their interest and suggestions slowly restored my confidence and enabled me to complete this thesis step by step.

The beginning of this Master's thesis journey was particularly rough. I faced possibly the most challenging time of my life when, before kicking off, my grandmother passed away, requiring me to go back and stay in Taiwan for an extended period. It was difficult for me to focus on my studies for a long time afterward. Honestly, I contemplated dropping out numerous times due to the fear of losing control over my schedule and doubts about my ability to achieve my goals both academically and professionally.

However, I am grateful for the immediate support from my supervisor team, enabling me to return swiftly. I'm also thankful for the support from my parents, my brother, and the encouragement from friends. They pushed me forward to accomplish this challenge, accompanying me through such a unique phase in my life.

I want to dedicate this thesis especially to my grandmother, Lin Huang Yuchai, who had been with me since I was young. Although she never really understood what I was studying or doing, she always took pride in me and worried that I was overworking myself for my studies. Over the past two years, we have said goodbye again and again, and she always patiently waited for my next return. This might be one of the biggest regrets of my life, not being able to let her witness my graduation. I hope, if she can see me successfully complete this thesis, she will be happy and proud of me from heaven.

Lastly, I want to express my gratitude to my family, my parents, and my brother Leo. Without their endless love and support from distant Taiwan over these two years, I wouldn't be where I am today. Thank them for supporting my pursuit of design, for supporting my education abroad, and for providing me with a warm home where I can always return to rest.

Being a designer is my dream, but without the support of these people, I couldn't have reached this point today. Completing this thesis today will mark a milestone in my life as a designer/researcher, but it doesn't mean it's the end. In the future, I will continue to strive and improve myself on this way.

Abbreviations used

Mental workload	**MWL**
Electroencephalography	**EEG**
Human-Computer Interaction	**HCI**
Personal Informatic	**PI**

Executive summary

Compared to well-known physiological body data such as blood pressure and heart rate, our understanding of what happens inside the brain is still limited.

The concept of **measuring Mental Workload (MWL)** has long been established, aiming to evaluate the balance between the cognitive resources required by users to complete a task and the resources currently at hand. With the advent of innovative technologies, it provides more up-to-date, comprehensive and objective cognitive data. However, the impact of such data on individuals, as well as their expectations and needs regarding this technology, presents areas worthy of exploration. It is also related to how to create a continuous self-tracking behavior.

Research goal

Accordingly, the purpose of this study is to **understand people's understanding and thoughts on MWL and to explore from the user's perspective how to establish meaningful self-tracking behavior of MWL.**

Phase I the exploratory period: literature review & interviews

In the exploratory phase of Phase I, the study first explore the **literature** to understand the definition of MWL and factors to consider for promoting self-tracking. After establishing a basic understanding, **interviews** were conducted to understand users' understanding, motivations, and needs for tracking MWL. Several important issues were defined, including cognitive data interpretation bias (usually associated with stress), data mistrust issues, lack of visibility of data impact, lack of connection, and data presentation format and timing.

Phase II verifying research findings through co-design: literature review, rapid prototype, user test and offline survey

In the second phase, to validate the previous research insights, co-design activities were conducted, inviting users to participate in two activities: user tests and surveys.

Before the user tests, another round of **literature review** was conducted based on the research insights from the first phase to explore potential solutions. Drawing from the directions identified through literature review and the design of metrics developed by existing products, EMOTIV, a **rapid prototype** was designed. This prototype served as a tool for **user test** to discuss user needs, identifying issues, and practical tracking experience with co-designers.

The **offline survey** invited users to record their workload and stress levels throughout a day from their perspective to understand how they perceive workload and why it may be confused with stress.

Phase III Reflection research conclusion, discussion, and recommendations of future design

The **third phase** involves **reflection** on the research findings. Combining the literature review and insights from validation, the research results are discussed, and future design recommendations are proposed.

Table of content

Chapter 01 Introducing the project — 1
1.1 Project Background 3
1.2 Project Problems 5
1.3 Research Questions 7
1.4 Approach 9
1.5 Project Limitation 11

Chapter 02 - Verifying Theory: from the users' perspective — 13
2.1 Related work 15
2.2 Research Methodology: Interviews 21
2.3 Interview Results 25
2.4 Conclusion of exploratory interview 37

Chapter 03 -From research to design verification — 39
3.1 From research to design solution 41
3.2 Related work 43
3.3 Conclusion: From solutions to design verification 49

Chapter 04 -Co design: User test — 53
4.1 Research Methodology: User test 55
4.2 Prototype Design 57
4.3 User Test Results 67
4.4 Conclusion of User Test 85

Chapter 05 -Co design: Survey — 87
5.1 Research Methodology: Survey 89
5.2 Booklet Design 90
5.3 Results of Survey 95
5.4 Conclusion of Survey 108

Chapter 06 -Conclusion and discussion — 109
6.1 Conclusion 111
6.2 Recommendations for future 119
6.3 designDiscussion 123

Appendix — 127
Reference — 129

Chapter 01

Introducing the project

1.0

This chapter introduces the background of the project and the issues it aims to address. Building upon these project problems, research questions are formulated, and an approach is defined to investigate these research questions.

1.1 Project Background

1.2 Project Problems

1.3 Research Questions

1.4 Approach

1.5 Project Limitation

1.1 Project Background

A transfer in measuring MWL

Mental workload (MWL) is defined as the perceived relationship between an individual's total mental processing capability and the amount required by the task at hand (Bagheri et al., 2020). As individuals navigate through various tasks and responsibilities, their cognitive state plays a pivotal role in determining performance, well-being, and overall productivity.

In the past, assessing MWL of personnel engaged in high-risk tasks, such as piloting aircraft, was crucial to preventing major errors. Apart from high-risk occupations, the highly automated nature of job content has magnified the impact of human errors, leading to a decrease in tolerance for mistakes. Ensuring an environment and job content that aligns with the capabilities and state of the workers has been a major goal in our past measurements of MWL.

However, in the rapidly evolving landscape of Human-Computer Interaction (HCI), the exploration of MWL has emerged as a focal point, driven by a growing desire to understand and optimize cognitive capabilities. Instead of creating a environment suits everyone, recent focus enphasizes in evaluating people’s MWL to place them in the right place.

To achieve the later objective, Neurotechnology (see definition and example on the next page), encompassing a diverse range of technologies and methodologies such as electroencephalography (EEG), and wearable brain-computer interfaces, has empowered researchers and practitioners to dive deeper into the neural mechanisms associated with MWL. These technologies are being employed to detect and track cognitive data, such as cognitive status, stress levels, and focus.

> **Create an environment and job content that aligns with the capabilities and state of the workers**
>
> ↓
>
> **Place people in the most suitable position by assessing their cognitive load**

1.2
Project Problems

"Problem keywords 1.
Novel but unfamiliar Neurotechnology

From the transition discussed in paragraph 1.1, we are shifting from a task-centered mindset to user-centered minset. In this case, wearables present a strength that allows us to continuously monitor an individual's state and offer real-time feedback.

These wearables equipped with Neurotechnology, involving the application of principles from neuroscience to develop tools, devices, and techniques for understanding and interacting with the brain and nervous system. In this research, the goal of applying Neurotechnology is to collect cognitive data.

However, it is anticipated to be an entirely novel concept for humans, stemming not only from Neurotechnology but also from the tracking outcomes, cognitive data. It remains unknown that what do people think of this technology and tracking cognitive data.

"Problem keywords 2.
Motivation of self-tracking cognitive data

On the other hand, this shift emphasizes the significance of the concept of self-tracking. As the assessment of MWL is no longer confined to task design but extends to everyday life, tracking at any time and place becomes possible. However, if users are unwilling to engage in self-tracking, the device becomes nothing more than mere rhetoric.

"Problem keywords 3.
Use scenario and needs of Neurotechnology from user perspective

Though these technologies are still new concepts for users, there are already numerous products on the market trying to utilize the analysis of EEG data or other physiological data such as heart rate and skin conductance to interpret people's current mental states. These products vary in functionality and employ different technologies, resulting in diverse sets of data and information, as illustrated in the table 1.2.1.

In contrast to the familiar physiological data trackers, which collect physiological and activity data to provide comprehensive insights and advice for fitness and health, current cognitive data trackers primarily rely on EEG data. These trackers then translate EEG data into various metrics, such as focus score and meditation score. These comparisons highlight several traits of Neurotechnology:

1. **Specific Use Scenario:** Neurotechnology often serves specific use cases, such as meditation, rather than offering generalized tracking.
2. **Derived Metrics Instead of Raw Data:** Unlike physiological data trackers that often display raw data like heart rate, cognitive data trackers provide derived metrics like focus score.

Based on the traits of current Neurotechnology used to track cognitive data, it seems these device are influenced and limited to cognitive data expertise or unique usage scenarios.

However, it remains uncertain whether these targeted scenario and data design align with users' needs. Not to mention that Neurotechnology do not enable unconscious tracking of brain waves as seamlessly as wearing a wristwatch. Compared to physiological data tracking, there are numerous new considerations worth being explored, such as will users be willing to have their brain wave data tracked 24/7 in the future? If not, when would it be considered appropriate to track cognitive data? What specific analyses would users want to perform with cognitive data? Do current cognitive metrics design align with users' needs?

Even if existing market products, like Emotiv or Muse, pave the way for everyday tracking of cognitive data, many questions still need to be addressed from the perspective of the user.

Table 1.2.1. *Comparisons between existing tracking products*

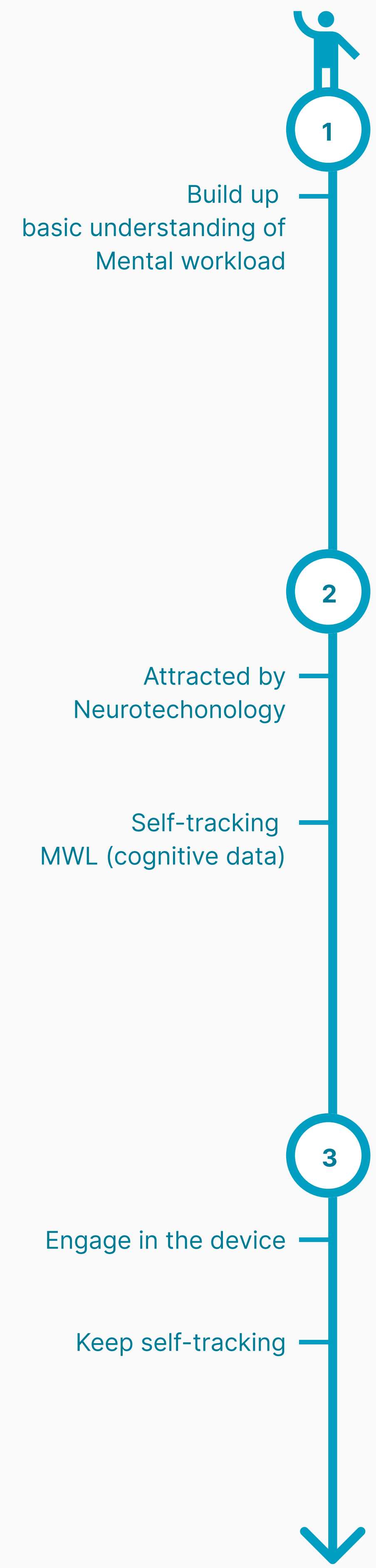
Tracker's Core Function	Through	Brands	Data gathered	Transfered information
Health and Fitness Ecosystem	Photoplethysmography (PPG), Accelerometer	Apple Watch	Heart rate, activity data	Heart rate trends, Activity rings, ECG recordings
Fitness Monitoring	Heart Rate Monitor, Accelerometer	Xiaomi Mi Band	Heart rate, activity data	Heart Rate Variability, Activity Level, Sleep Quality
Meditation Tracking	EEG	Muse S	Brainwave patterns	Meditation Score, Sleep Patterns, Mindfulness Level
Focus Tracking	EEG	NEUROSITY	Brainwave patterns	Focus Score, Mental Workload, Cognitive Engagement
Cognitive Workload Tracking	EEG	Emotiv	Brainwave patterns	Cognitive Workload, Focus Level, Mental Engagement

1.3
Research Goal and Questions

Moving forward from the observed shift and three problems articulated in the chapter 1.2, this research formulates the **main research goal** and **questions** accordingly.

Research Goal
The main goal of this study is **to bridge the gap between traditional methods of measuring mental workload and the utilization of wearable neurotechnology for measuring mental workload.**

Research Problem	Research Question
Problem 1. Novel but unfamiliar Neurotechnology	**RQ1.** What do people understand Mental Workload in terms of this terms and the outcome of this technology?
Problem 2. Motivation of self-tracking cognitive data	**RQ2.** How to motivate people to self-track their Mental workload through this technology?
Problem 3. Use scenario and needs of neurotechnology from user perspective	**RQ3.** What are the user needs when self-tracking Mental workload?



The first research question involves how do people understand the concept of MWL. As a novel technology and new concept of measuring cognitive data, there are some potential sub-questions worth exploring:

- Will user correctly perceive the meaning of tracking Mental Workload?
- What is the understanding of Mental Workload from users' perspective?

The second research question refers to how to motivate and attracy users formulate a self-tracking behavior? To make people actively track their cognitive data, some potential questions needed clarify:

- If the design of current neruotechnology enough to encourge people keep self-tracking their cognitive data?
- If not, how to stimulate a self-tracking motivation on cognitive data?

The third research question discussed the design to stick users on this technology after starting using this technology. To achieve it, the design is supposed to correspond with user need and expectations. As a result, several user research becomes crucial as:

- If the contents and functions in current technology align with user need?
- What are the expectations on this technology from users' perspective?

1.4
Project Scope and Approach

According to the project problems in chapter 1.3, the scope of this project is further depicted as shown in the figure1.4.1.

There are three key elements in this research: Theory of MWL, Neruotechnology, and device users. The overlapped sections are User understanding (refers to RQ1), Self-tracking scenario (refers to RQ2) and User needs (refers to RQ3).

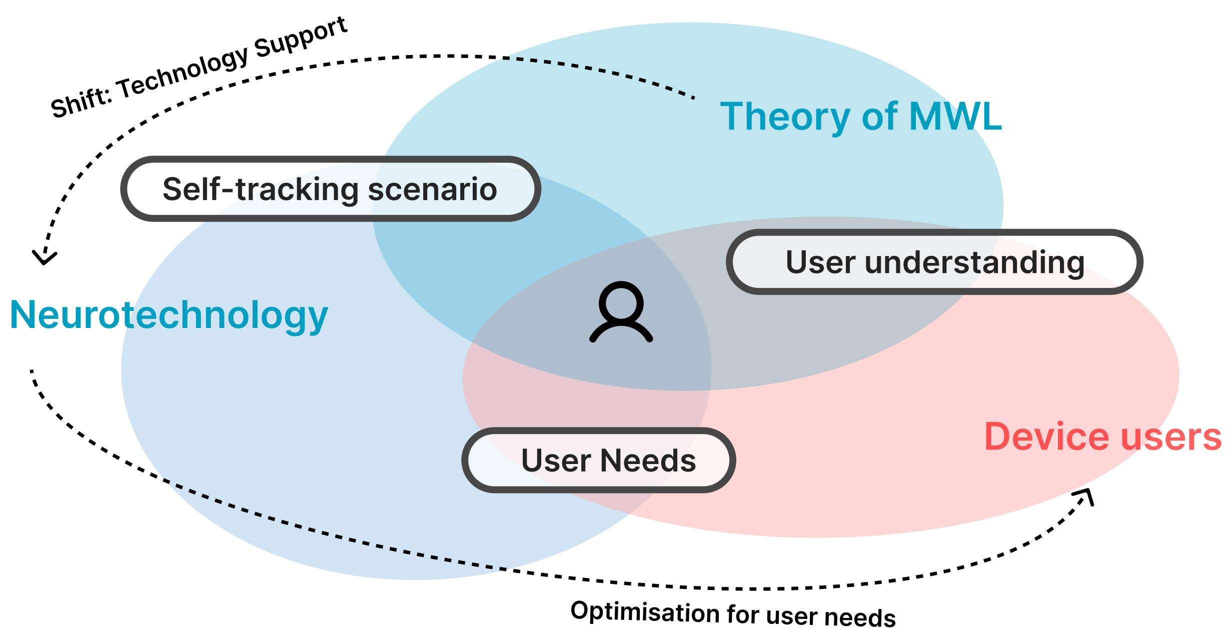


Fig 1.4.1 Project scope

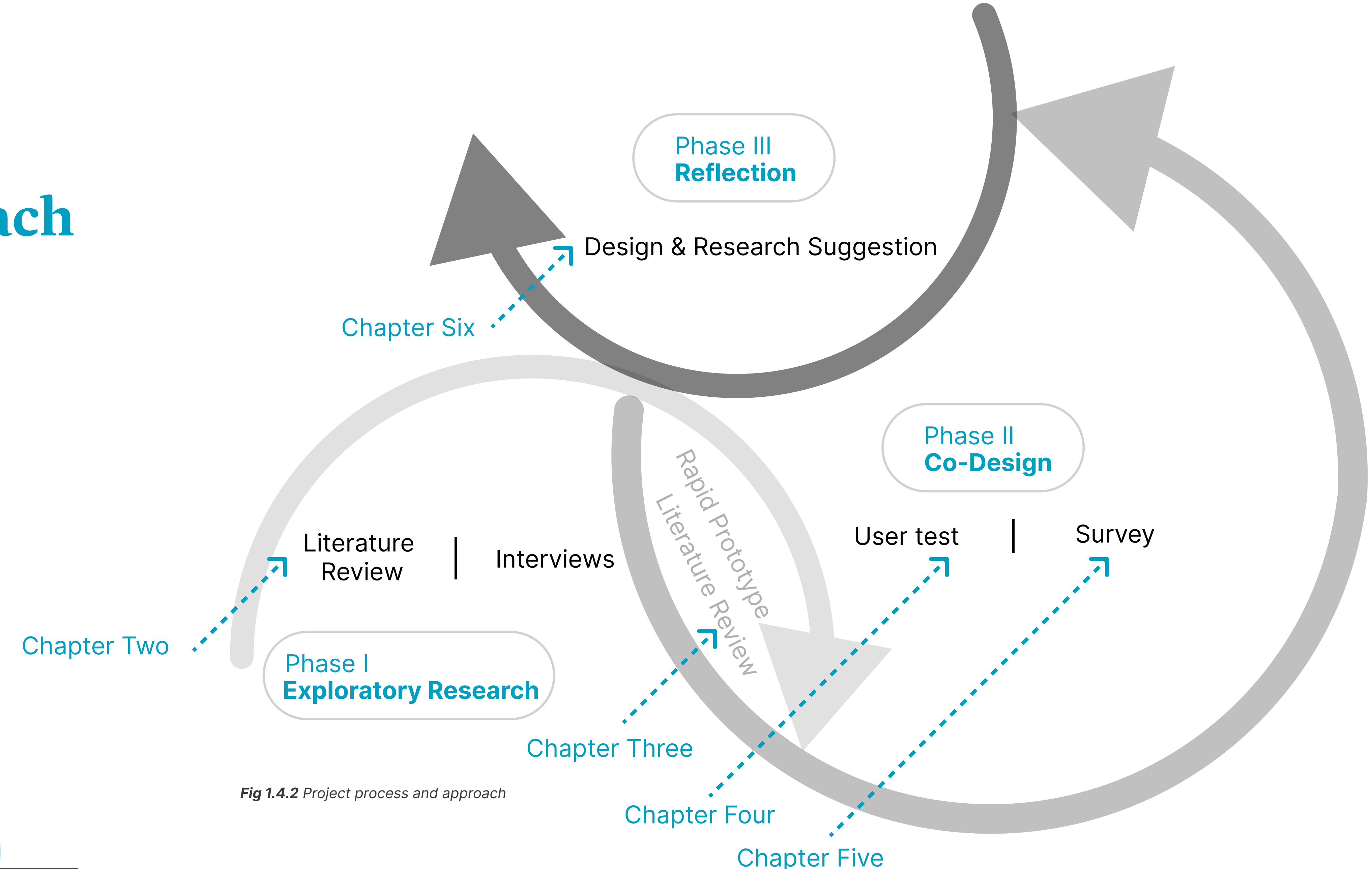


Fig 1.4.2 Project process and approach

The overall research process is divided into three phases: Exploratory Research, Co-Design, Reflection (Fig 1.4.2).

Phase I focus on building up theory background and verifying it through interviews with users. Literature review and semi-structure interview are conducted during phase 1. The expected outcome of this phase includes theory definition, users' views on MWL, and user personas , which can be found in chapter 2.

In the transition between Phase I and Phase II, a rapid prototype is generated based on the insights from Phase I.

In **Phase II**, the core activities is surrounding co-design, which aims to explore the concept with real users and integrate their opinions into design suggestions. User test and an offline survey are conducted to verify users' needs and expectations about recording MWL.

In the end of the research, **Phase III** will reflect on the Phase I and Phase II's gains and generate future design suggestions.

1.5
Project limitation

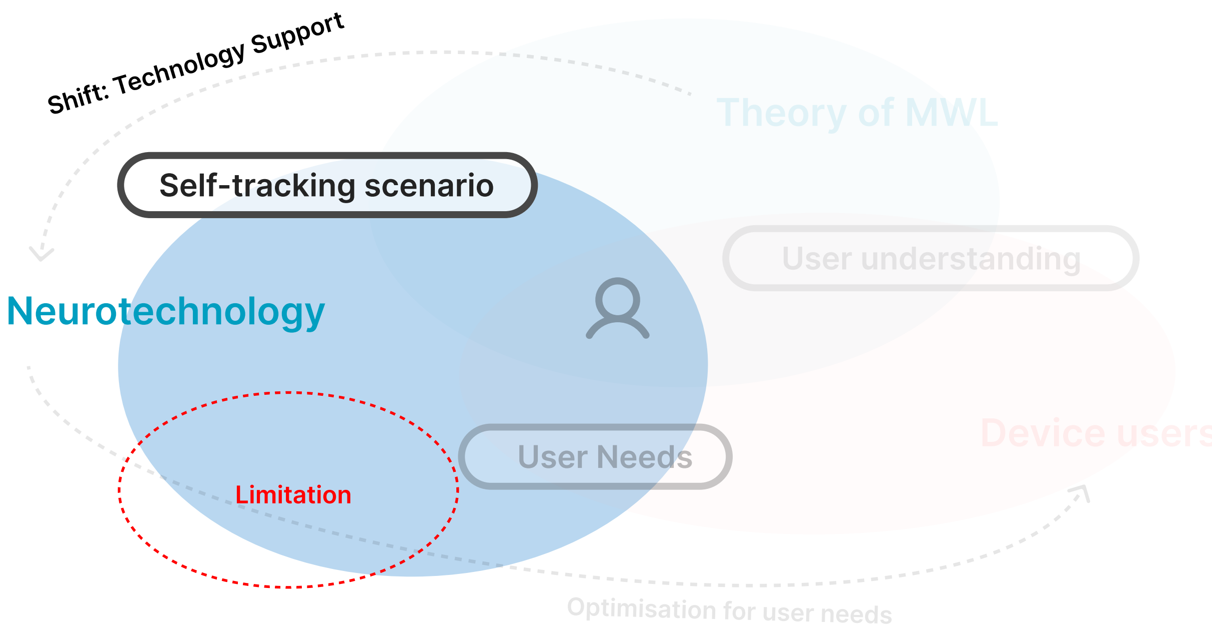


Fig 1.5.1. *Project limitation*

As illustrated in Figure 1.5.1, this study's scope encompasses the utilization of Neurotechnology. However, it is important to acknowledge a limitation within the project regarding Neurotechonology.

Neurotechnology remains a relatively new field for people, however, there are already various products on the market used for tracking MWL or Workload. In pursuit of practicality, this study is expected to reference existing technologies such as metric design. However, it is impractical to refer to every metric from numerous Neurotechnology products, as each one is positioned uniquely with diverse primary functions. Therefore, reference product selection will be limited based on the research objectives. Additionally, cognitive data tracking products may encounter issues of data inaccuracy due to immature hardware design and technological development challenges. Thus, this study will not focus on data collection but rather on exploring user needs.

Chapter 02

Verifying Theory: from the users' perspective

2.0

This chapter will begin with a number of literature reviews, exploring the basic definition of MWL and potential issues or challenges that may arise during the transition from traditional measurement of MWL to using wearable technology. Based on the literature review, an exploratory interview is planned during this phase, aiming to investigate the significance of self-tracking MWL from the user's point of view.

2.1 Related work

2.2 Research Methodology: Interviews

2.3 Interview Results

2.4 Conclusion of exploratory interview

2.1 Related work

In general, this research is centered around MWL, and the research goal is to fill the gap between traditional MWL measurement and applying it with Neurotechnology. To answer the project question 1 and 2 (refer to chapter 1.2), it is crucial to understand the theory of MWL, Neurotechnology (represented by EMOTIV tracker), and how to build a self-tracking behavior. Therefore, the following literature review will focus on building a basic understanding of MWL, starting from "Mental workload" and ending in "Self-tracking" (Fig.2.1.1).

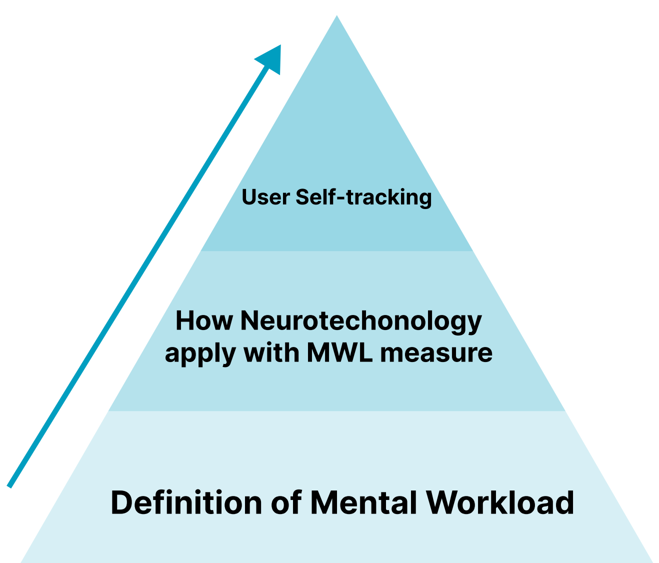


Fig 2.2.1. *Structure of literature review*

Measuring Mental Workload

Continuously monitoring MWL provides new opportunities to support the prevention of mental disorders and maintain psychological health. At times, task-related MWL measurements serve as an additional safeguard, especially in high-risk occupations, to reduce the occurrence of major and potentially fatal accidents (Gagnon et al., 2012). With the increased consequences of errors in highly automated industrial settings, efforts have been focused on reducing predictable human errors. This is why the concept of measuring MWL has become prevalent in the field of HCI in recent years. However, there is no universal definition of MWL (Cain, 2007). The concept of MWL has evolved from the term "workload" since the 1970s.

Stem from "Workload"

Gopher et al. (1986) define "workload" as a latent variable that affects individuals' performance in task operations. It may be influenced by various factors, as outlined by Lysaght et al. (1989), who categorized workload definitions into three categories: actual work quantity, time spent on tasks, and subjective psychological experiences. The diverse demands on operators in different tasks make it challenging to establish an objective measure of workload for a task (Casali et al., 1984).

However, it has been observed that much of the work-related stress occurs when individuals endure inappropriate workloads (Wilson, 2002). Prolonged exposure to such conditions may lead to chronic stress, depression, and other psychological issues.

Current Measurements of "Workload": Scale

In recent year, various tools have been employed to measure workload, including the NASA Task Load Index (TLX) (See Fig 2.1.2) and the Subjective Workload Assessment Technique (SWAT) (See Fig 2.1.3), widely utilized in fields such as aviation and healthcare research. The NASA TLX assesses six dimensions: mental demands, physical demands, temporal demands, performance, effort, and frustration (Hart et al., 1988). Conversely, SWAT (Reid et al., 1988) focuses on measuring three dimensions: time load, mental effort, and psychological stress.

While these tools differ in their use, they have proven effectiveness. Due to their different emphases, the applicability of questionnaires varies depending on the task context. For instance, NASA TLX excels in predicting performance in specific tasks, while SWAT is suitable for analyzing the cognitive demand required in a particular task (Rubio et al., 2004).

It seems that both scales aim to measure 'workload,' although their specific assessment points may differ a bit. However, there are still some commonalities include 'mental effort load,' 'time load,' and 'stress.' Interestingly, these three assessment points cover the three types of workload proposed by Lysaght et al (1989). That is, even though different individuals may perceive workloads differently, integrating various perceptions of workload into a single form can help avoid overly subjective judgments, providing a relatively objective outcome, which is kind of benefits of using scales to measure Workload.

Limitation of Scales

Workload scales also come with numerous limitations. For example, in tasks like TLX and SWAT, participants are typically required to complete questionnaires after task completion to gauge their perceived workload. The completion of these questionnaires takes approximately one hour. These task-centric measurement tools, especially in safety-critical situations (Young et al., 2015), entail participants spending a significant amount of time assessing their workload after tasks. On the other hand, it indicates the challenges to use these measurements when deviating from rigorous control conditions (fixed contexts, single tasks) (Midha et al., 2022).

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Fig 2.1.2. *Scale of NASA Task Load Index (TLX), (Hart et al., 1988)*

I. Time Load

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.
2. Occasionally have spare time. Interruptions or overlap among activities occur infrequently.
3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

II. Mental Effort Load

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.
2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainly, unpredictability, or unfamiliarity. Considerable attention required.
3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

III. Psychological Stress Load

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.
2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
3. High to very intense stress due to confusion, frustration, or anxiety. High extreme determination and self-control required.

Fig 2.1.3. *Scale of Subjective Workload Assessment Technique (SWAT), (Reid et al., 1988)*

Current Measurements of "Workload" : From Scales to applying Neurotechnology

With the advent of new technologies, neuroscientists have discovered that certain brainwaves in an individual's EEG data can be used to interpret workload. For example, there are five types of brainwaves in EEG data: β, θ, α, δ, and γ brainwaves (Fig 2.1.4). These brainwaves coexist in our brains but have different meanings. For instance, δ brainwaves indicate that the brain is in deep sleep, characterized by less dense and more relaxed waveforms. α represents a state of just the right relaxation, while θ brainwaves, positioned in between, indicate an unconscious and shallow relaxation state, often used to identify entry into a meditative state. β and γ brainwaves exhibit more dense waveforms, reflecting a heightened state of brain activity when processing complex problems or engaging in deep thought.

Research indicated that observing these brainwaves can generally categorize people's states into different states when handling complex tasks: normal states of alertness, mental fatigue, and relaxation states. (Fig 2.1.5) An intriguing aspect is the presence of θ brainwaves, which can sometimes be referred as the "flow state." which signifies that individuals gradually require less cognitive effort to accomplish tasks. By cross-calculating these values, we can more accurately identify different mental states in individuals (Ranchet et al., 2017).

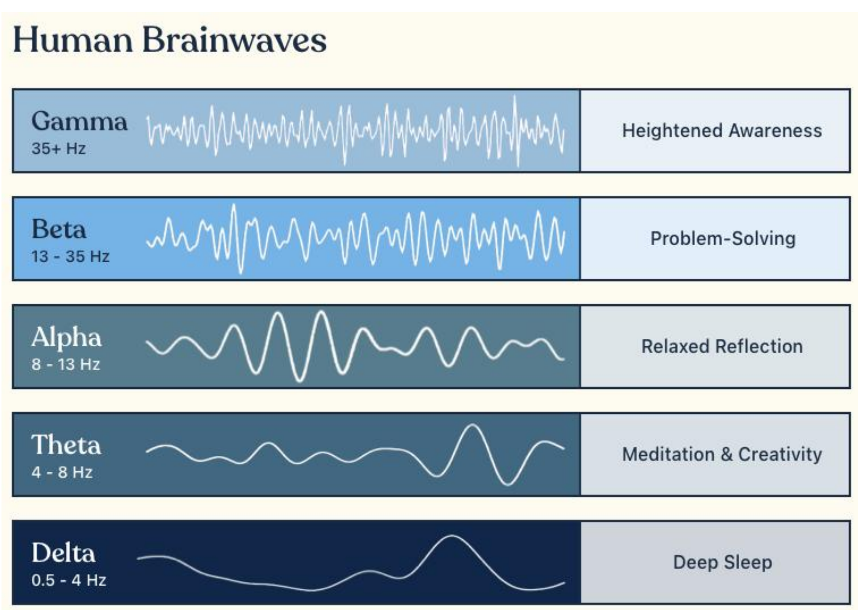


Fig 2.1.4. Five brainwaves related to mental conditions (Shashidhar et al., 2023)

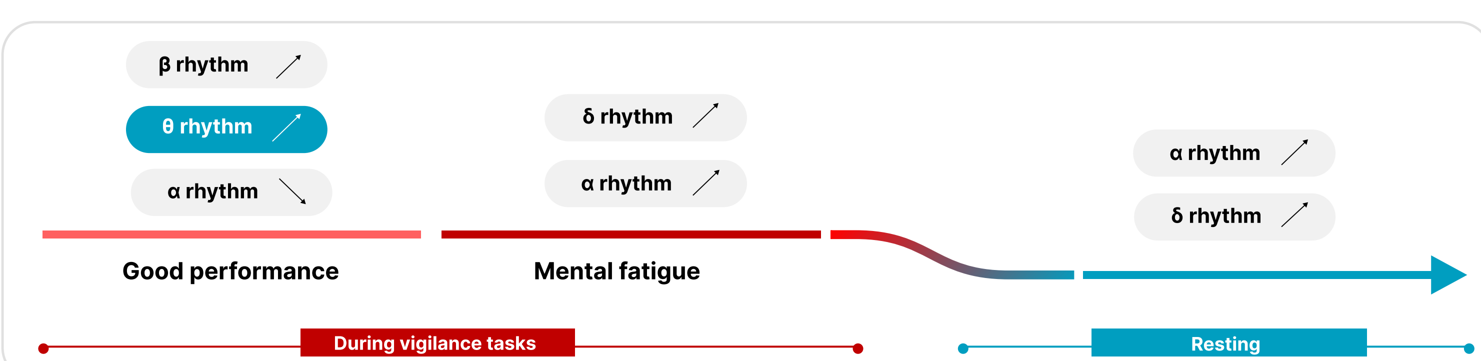


Fig 2.1.5. Brain Wave Changes in Different Mental States

Disparity between WL and MWL

While people have developed some relatively objective ways to measure workload, there still exists some disparity between the definitions of workload and MWL.

The term MWL lacks a precise definition, it generally refers to the relationship between task demands on individuals, the experiences individuals have during tasks, and the maximum capacity individuals can offer to tasks. Bagheri et al. (2020) define MWL as the perceived relationship between an individual's total mental processing capability and the amount required by the task at hand.

The results obtained from both paper-based scales and neurotechnology are still more like the "workload" perceived by individuals in the current context. Users can not know 'the amount of workload required by the task at hand' and cannot judge whether the workload they have used and the workload required achieve balance.

Though scales do measure 'the amount of workload required by the task at hand', the way it evaluates is through repeated scale evaluations by different individuals in a tightly controlled experimental environment. On the other hand, it is centered around "work" rather than around "people" to quantify different individuals' workload and identify the workload content, environment, and worker's ability that best fit the work context, instead of judging if a person's workload fit this context.

Subjective Mental Workload Rating

Though we do have the technology to measure workload now, directly measuring whether a task exceeds an individual's specific capabilities remains challenging. Mechkati et al. (1992) proposed three types of MWL measurement methods: performance-based, perceived effort-based, and physiological activation-based. Regardless of the measurement method used, the results are subjective, influenced by individual personal preferance. In addition to the measurement of MWL, Estes's (2015) research also indicates that people's perception of workload is highly subjective; as shown in Figure 2.1.6, individuals' perception of the increase in workload intensity is non-linear, possibly sharply decreasing when workload reaches a certain level, and may vary based on different personal situations.

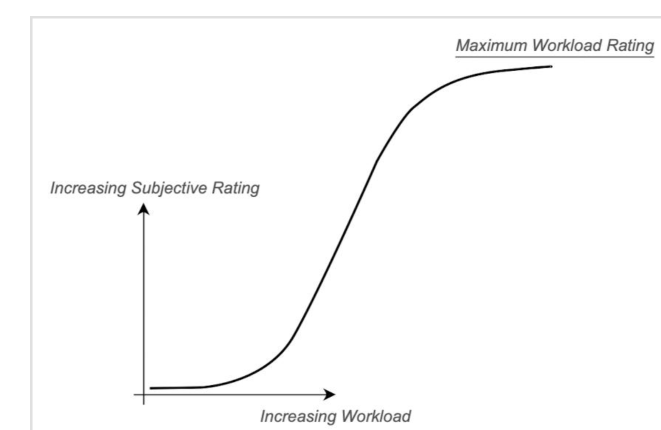


Fig 2.1.6. The subjective workload curve, (Estes, 2015)

Self-tracking MWL

Considering other factors when measuring MWL

As mentioned in the previous paragraph, measuring MWL and Workload are two distinct concepts. Workload is more related to a person's response to different situations, while MWL involves considering the conditions of various situations for workload's comparison and assessment.

Annett (2002) specifies that MWL is affected by the individual's goals, motivation, and plans. Jex (1988) pointed out that the measurement of MWL is influenced by people's cognitive processing of attention, goals, strategies, task complexity, and task performance. Even when measured through physiological parameters, it is still subject to the influence of individuals' consciousness, such as whether individuals would like to continue monitoring (Mihevic, 1981).

MWL as personal informatic (PI)

In fact, when individuals track MWL or Workload through a tracker instead of traditional scales, MWL or WL is transformed into a form of personal informatics. Personal Informatics refers to quantifying daily life into data through self-tracking (Epstein et al., 2015) and optimizing life based on this data (Rapp et al., 2017). The emergence of wearable technology enables more automatic collection of Personal Informatics.

However, the primary purpose of Personal Informatics is to enhance individuals' self-reflection and self-awareness or to understand factors that may impact their lives. Rapp et al. (2017) point out that such reflection is not aimed at changing external behavior or calculating utilitarian gains and losses, but rather achieving better self-understanding for individuals.

Five stage model of self-tracking PI

According to Li et al. (2010), the model of self-tracking Personal Informatics (PI) consists of five main stages: Preparation, Collection, Integration, Reflection, and Action (Fig 2.1.7).

Preparation explores the motivations behind individuals' initiation of tracking, which could range from having a specific goal such as weight loss to mere curiosity. Depending on the purpose, there are various tracking motivations.

Collecting describes the process of actively gathering data by individuals. **Integration** involves transforming and preparing the data for users to engage in reflection. In terms of the Collection and Integration stages, advancements in wearable technology and portable devices significantly facilitate the automatic collection of personal data and streamline the generation of integrated information.

The final stages, **Reflection** and **Action**, are particularly emphasized by Rapp et al. (2017). Reflection involves understanding the data and choosing how to react based on newfound self-understanding. While action may not always be taken, individuals sometimes opt to maintain the status quo.

According to the self-tracking Personal Informatics model, there are many aspects related to user research worth exploring, such as user motivation, timing of tracking, and so on.

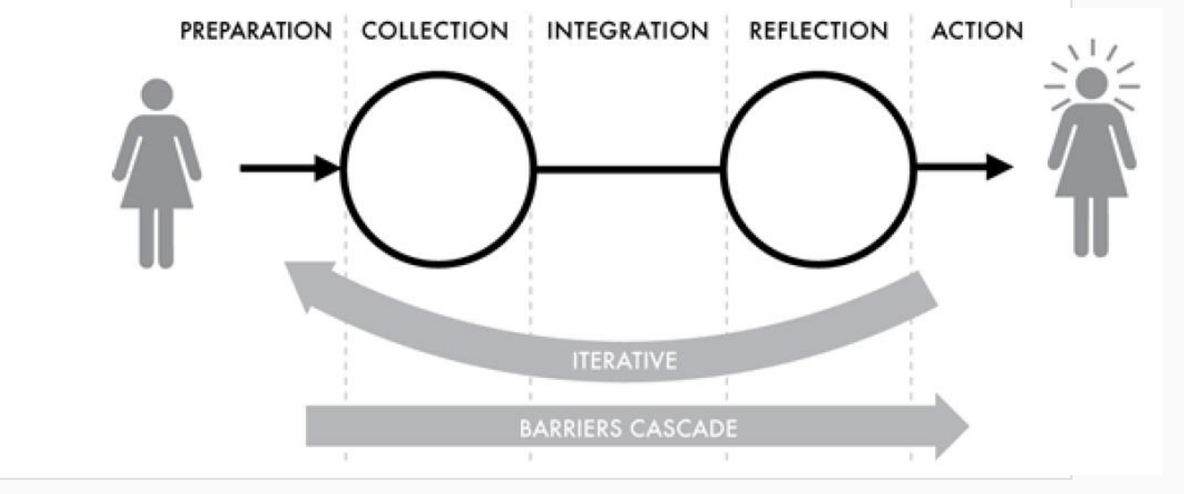


Fig 2.1.7. *Five stages of self-tracking PI (Li et al., 2010)*

2.2
Research Methodology: Interviews

Interview Questions

Refer to Li et al (2010)'s five-stage personal informatic self-tracking model and apply it into measuring MWL, there are several questions worth exploring with users.

Firstly, during preparation stage, users will think about what information to collect. Questions arise here as

- how do people understanding "Mental Workload" this term?
- what do people expect from these data gathering?

In the second phase, collecting, which is namely using the device and collect their MWL data, one basic question comes as

- when will users want to collect their MWL data and for what reasons at those moments?

The third phase, integration, becomes less difficulties by means of technology aiding. If referring back to existing products like EMOTIV, they provide users with several integrated metrics, like score of stress and focus, instead of directly showing them brain waves, which are supposed to be hardly understood. However, when users moving to the next stage, reflections, questions appear.

- If these metrics mean a lot for users?
- What kind of reflection do people expect in this stage?

Accordingly, this interview is primarily divided into five parts: tracking experience, defining MWL, drawing MWL, measuring MWL, and reflecting on MWL.

Tracking Experience as a warm-up topic, encourages people who do not have experience of neurotechnology to recall relevant experience of tracking health data. In addition, The aim of this section is to understand the participants' motivation and experiences related to their self-tracking.

Next, in **Defining MWL** and **Drawing MWL** section, participants are required to explain MWL in their language and describe their daily MWL. To help articulation, this sections show participants a sample graph and observe how participants explain it. The results of this section is supposed to contribute to build up "preparation stage" in five-stage self-tracking PI model.

The last two parts, **Mearsuing MWL** and **Reflecting MWL,** which align with "reflection stage" in five-stage model, this study references the user interfaces of Emotiv, selecting three types of pictures: graph (Fig 2.2.1), visualized images (Fig 2.2.2), and metrics (Fig 2.2.3). These are then presented to participants for their interpretation and reflections. Especially, regarding the metrics, there is a particular emphasis on participants' definitions of MWL quality and their goals for using the data. Lastly, the discussion explores how users would integrate this tracking behavior with their daily lives. Detailed questions could be found in Table 2.2.1.

Table 2.2.1. Exploratory Interview Questions

Keypoints	Research Goal	
Tracking experience (warm-up)	Users' self-tracking experience	1. have you used any fitness/cognitive trackers in the past? If so, which ones and what were you tracking? 2. what kind of devices do you usually use? 3. How long have you had this habit? 4. What do you value in this process?
Defining MWL	Users' explanations of terms " Mental workload v.s Cognitive workload "	1. What does mental/cognition load mean for you?
Drawing MWL	Users' descriptions of their daily MWL	1. Can give me 2-3 examples of the moment you feel you are in high or low MWL? 2. How will you describe your today's mental workload?
	Users' explanations of their daily MWL *Show them a graph	1. What information attracts you most? why? 2. What do you think is missing? why
Measuring MWL	Users' perspectives on the MWL metric	1. What do you think good or bad cognitive/mental condition means? 2. What would be your goal to track your mental health condition?
Reflecting MWL	connection between life to MWL	1. What are the moments you remember most about your day and why? 2. What are things worth tracking in your life? 3. Do you think your life is static or varied? Which do you prefer? 4. How often do you reflect on your mental / cognitive health - and why?

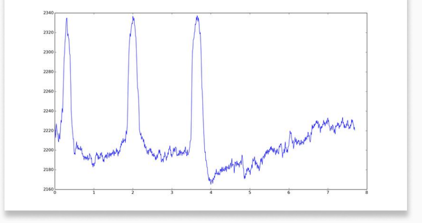


Fig 2.2.1. Interview tools: graph

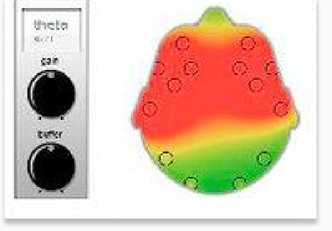


Fig 2.2.2. Interview tools: virualized images

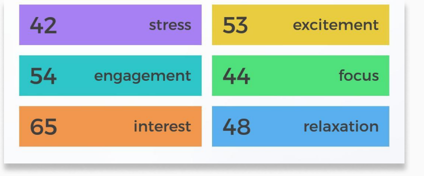


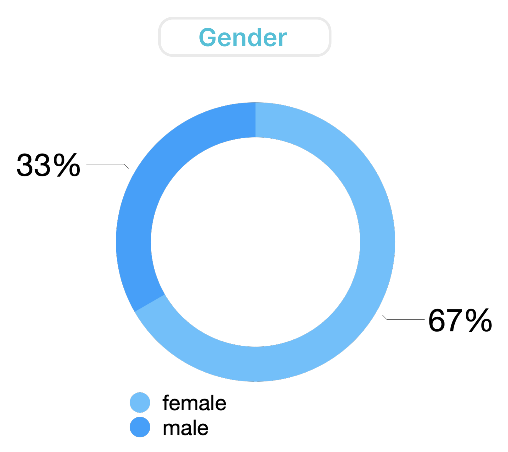
Fig 2.2.3. Interview tools: metrics

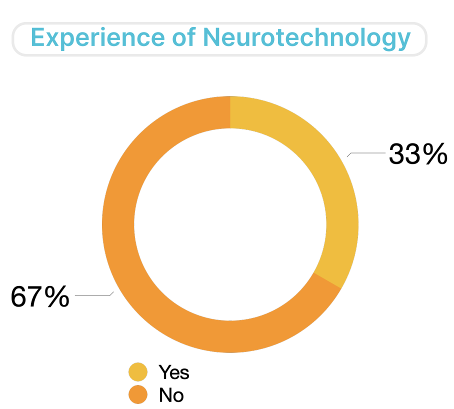
Methodology & Recruitment

The **semi-structured interview** was the primary method to explore users' views and is conducted online through the app "Zoom.us". **Six participants** were recruited in total and through snowball sampling. The research didn't require any specific background as everyone could be the users of Neurotechnology device. Considering diversity of life, values and economic capacity, this research reached out to three students and three non-students. For privacy issues, six participants were numbered from S1 to S3 and W1 to W3, "S" refers to students and "W" refers to office workers. Detailed information could be found in Table 2.2.2.

Table 2.2.2. *Description of Interview Participants*

	Num.	Background	Gender	Experience of Neurotechnology
Student	S1	Industrial design	F	N
	S2	Material science	F	N
	S3	Architecture	F	N
Non-Student	W1	Financial Risk Management	F	N
	W2	Judges' assistants	M	Y
	W3	Engineer	M	Y





Research Procedure

The interview takes around one hour in total, including giving short introduction, interview, and final debriefing. The whole process is shown in Fig 2.2.1.

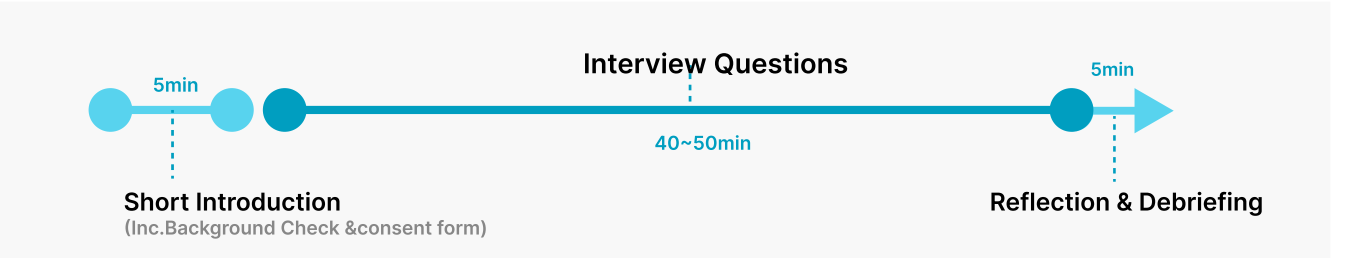


Fig 2.2.1. *Interview Process*

Data Analysis

As this interivew is primarily exploring users' "Attitude" and "Opinions" on MWL, the discussion of the interview will be analyzed through **inductive thematic analysis,** which is wildly used to find out people's views, opinions, knowledge, experiences or values from a set of qualitative data. (Daly et al., 1997). The main analytical process is divided into six steps (Braun et al., 2006):

1. Familiarizing yourself with your data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report

During the analysis, in-vivo codes would be extracted from interview transcript, and be put into different categories, so called initial categories. Then, initial categories would be clustered to form initial themes. In the end, those initial themes will be refined to generate final themes(Fig 2.2.2).

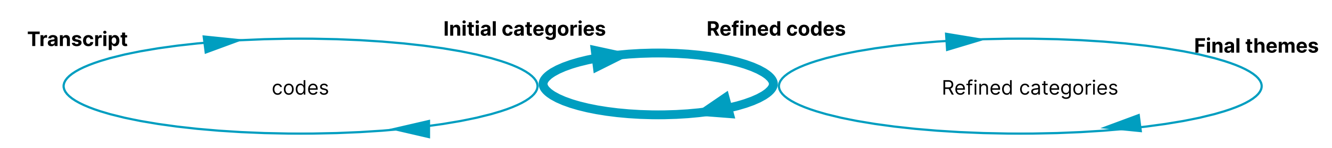


Fig 2.2.2. *Analysis Process*

2.3
Interview Results

After conducting thematic analysis, 123 codes, 19 initial categories, 38 initial codes and 9 refined categories are generated, which ultimately leads to five final themes (Fig 2.3.1).

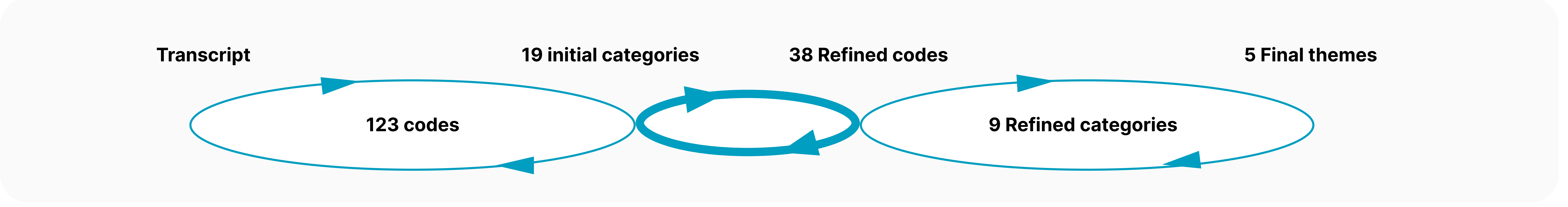


Fig 2.3.1. *Results of Interview analysis*

Overview of 19 Initial categories

The verbatim transcripts from six individuals generated a total of 123 codes. These codes were then categorized into 19 initial categories, named according to **deducted interview themes (see table 2.3.1)** such as "Ideal Mental Workload," "Cognitive Load and Mental Load," and **frequently recurring inducted terms and topics (see table 2.3.2)** like "Accuracy," and "Timing".

The overview (Fig 2.3.2) of deducted and inducted categories can be found below, with the number of how many participants mentioned each categories.

means how many participants mentioned it

Deducted categories from interview themes

- MWL (defining Mental Workload)
- Metric
- High MWL
- Recall
- Data perception
- Mental Load
- Comparison between high and low MWL
- Ideal MWL
- Low MWL
- Cognition Load

Inducted categories from high-repetition words or topics

- Accuracy
- Tracker Function
- Attitude
- Needs & goals
- Timing
- Motivation
- Health awareness
- Changes/taking actions

Fig 2.3.2. Overview of 19 initial categories

First layer insights: based on quantity of initial categories

High correlation between Stress and MWL

The results indicates that a significant number of participants (5 out of 6) associate mental workload (MWL) with stress or use stress to explain high levels of MWL (5 out of 6). When asked separately about participants' explanations of cognitive load and mental workload, "Mental Load" is a term that users find easier to understand, often explained using words such as "emotion" and "stress." In contrast, although the explanation of cognitive load is more specific, fewer people (3 out of 6) could provide explanations. From the results, it is difficult to determine which participant's answers are closer to the correct answer, but it appears that emotions and stress are the most familiar terms and expressions to people, and they play a significant role in their lives.

"I'm thinking... it [Mental Workload] might be a kind of emotional accumulation. Like, you may have negative emotions that keep accumulating over time. Otherwise, it could be that your mind is consistently in a stressed state. (S2)"

Difficult to explain or understand

In addition, among the deducted categories (see table 2.2.1), most topics are straightforward to discuss, such as explaining Mental Workload (MWL), discussing metrics, identifying high MWL instances, and reflecting on past experiences. However, three categories received less attention. "Good MWL" and "low MWL" are observed to be challenging to explain. Out of six participants, three were unable to articulate their ideal MWL, and three expressed uncertainty about what constitutes a low level of MWL and how to make an example for it.

"Low-level mental workload might involve doing simple things... it's a bit tricky to come up with an example (S2)"

"If I'm just resting, not thinking about anything, is there still any workload? ...I mean... The difference between not doing anything and engaging in low-level mental workload is...? (W2)"

Attention on Peak points

The interview results revealed that whether people recall their performance throughout the day or simply their daily activities, the most memorable points always seem to occur at peak moments. These peak moments may occur during high mental workload (5/6), busiest times (6/6), the accomplishment of the most significant goals of the day (2/6), emotionally intense moments (2/6), or things that doesn't fit the routine (4/6) and so on. It seems that people's impressions often linger on the most intense experiences, leading them to subconsciously link these intense feelings together. For example, when distinguishing between levels of mental workload (MWL), individuals may subconsciously associate high MWL with a high quantity of something, such as some participants associating high MWL with high stress or high workload involving significant thinking. In this regard, while we lack definitive answers, it's evident that individuals

***Table 2.3.1** Initial deducted codes & categories*

initial categories	Codes
MWL (6/6)	**Accumulated stress (5/6)**
	Brain efficacy(1/6)
	Psychological limitation(3/6)
	The willingness to do something (1/6)
	Adjectives, like normal, challenging, relaxed (3/6)
High MWL (6/6)	Fully attention (3/6)
	Stress (5/6)
	Feeling uncontrollable (2/6)
	Emotional issues (2/6)
	High workload (1/6)
Low MWL (4/6)	Uncertainty about the definition of low MWL and doing nothing (2/6)
	Hard to specify low MWL (3/6)
	Not difficult (1/6)
	Less focus (2/6)
	Less thinking (2/6)
Tell the difference between high and low MWL (4/6)	More or less thinking (2/6)
	Whether achieve the goal of that day (2/6)
	Through activities (3/6) -highMWL: reading(1/6), socialize(2/6) -lowMWL:doing laundry(1/6)
	MWL level changing due to procrastination (1/6)
Data perception (6/6)	Separate "peak" and "lowest points" and "not idea state" (2/6)
	Focus on peak points (2/6)
	Sense of Panic (2/6)
	Focus on significant fluctuation (2/6)
	Focus on the average (2/6)

initial categories	Codes
Cognition Load (3/6)	Familiar but abstract (2/6)
	Understanding the world (2/6)
	Practically doing things (1/6)
	How much effort needed for a task (1/6)
	Rational (3/6)
	External (2/6)
	Quantifiable (1/6)
Mental Load (5/6)	**Emotion (5/6)**
	Stress (5/6)
	Prolonged influences (1/6)
	Tangible (2/6)
	Popular Issues (2/6)
	Emotional (3/6)
Ideal MWL (3/6)	**Adequate values and duration (2/6)**
	A bit challenging (2/6)
	Prevent negative emotions or lack of concentration (1/6)
Recall (6/6)	**Recall theme (6/6)**
	Typical day and day-off (4/6)
	Unnecessary tracking: trivia (3/6)
	Significant emotion change (2/6)
	Fixed recall theme (2/6)
	Meaningful and connected (1/6)
	Out of original plan (4/6)

tend to concentrate on the peak moments of each event. This suggests that smaller details may be unconsciously overlooked or disregarded.

Identifying one to two primary functions

Whether describing past tracking experiences or expressing expectations for measuring MWL technology, most interviewees mention one to two primary tracker functions in average. Interestingly, when compiling the functions mentioned by all six individuals, it becomes apparent that the same tracker have so many definitions for users.

Primary focus on verifying and exploring personal bodily reactions

From the interviews with the six individuals, various motivations for tracking personal data emerged. However, the most commonly mentioned motivations by the majority of participants (4/6) are "Verify body reaction" and "Needs to understand the causes of negative status, stress." The reason behind this is that people feel that despite their familiarity with their bodies, there are still many aspects that remain unclear to them. The greatest benefit of using trackers for them lies in the ability of these trackers to provide information that is not visible to the naked eye, helping individuals better understand their physical and psychological conditions.

The importance of reflection timing

Although the interview guide initially intended to inquire about what kinds of "events" are worth tracking cognitive conditions, participants' responses leaned more towards describing "moments/timing" rather than events. Almost every participant mentioned the timing they desire to "reflect on data." For users, compared to tracking data, "reflection" is seen more as an action. Moreover, several participants discussed negative outcomes when reflecting during tasks, such as experiencing even more stress (2/6), feeling distracted (4/6), or finding it not helpful (2/6).

Negative attitude in general

From the descriptions provided by the participants, it is evident that many individuals hold negative attitudes towards tracking personal information. Some attitudes may be merely passive, such as indifference towards data (3/6) or reluctance to change the current status quo (2/6). However, the most significant reason for negative attitudes discovered in this research is "no new information" (4/6). Rather than being passive attitudes that deter them from trying tracking, individuals' attitudes often turn negative after realizing they haven't "absorbed new information" from the use of trackers. It could also be attributed to excessive self-confidence in their situation, believing that trackers cannot provide them with new information. Overall, users' attitudes tend to be more about assessing what changes the data could bring them and whether it's worth their effort to use it.

Too confident on Mental Health

Many participants (4/6) mentioned the issue of "mental health" and believed that MWL might be related to mental health. However, interestingly, quite a few participants (2/6) also believed that they had no problems with their mental health. Actually, they differentiate between "emotional issues" and "mental health". Perhaps in the short term, people might experience emotional issues, such as feeling particularly stressed during certain periods, but in the long term, they believed they didn't have mental health problems. Therefore, mental health was not considered an important issue for the participants of this study, indicating that awareness of this issue may not be as prioritized among the general public.

Table 2.3.2. *Initial inducted codes & categories*

initial categories	Codes
Tracker functions (6/6)	Verify device (2/6)
	Behavior record (1/6)
	Seeking quality score (2/6)
	Reminder (2/6)
	Adjustment (2/6)
Motivation (5/6)	First experience (2/6)
	Fun (1/6)
	Personal affection (1/6)
	Verify body reaction(4/6)
	A Sense of Achievement (1/6)
	Self-exploring (3/6)
	Curiosity and novelty(2/6)
	Efficiency and Focus (3/6)
	Health decline (1/6)
	Feeling uncontrollable (2/6)
	Needs to understand the causes of negative status, stress (4/6)
Timing (6/6)	Reflecting when feeling negative (3/6)
	Reflecting afterwards (6/6) (i.g. after go home, after task)
	Tracking timing (4/6)
	Not helpful during the task (2/6)
	More stress during the task (2/6)
	Distracting during the task (4/6)
Attitude (6/6)	Passive selecting trackers (2/6)
	Passive attitude of knowing current status (3/6)
	Invaded privacy (1/6)
	No need to change current status (2/6)
	Seeking for scientific proof (1/6)
	No new information (4/6) (all already known)
Health awareness (5/6)	**Emotion health awareness (4/6)**
	Thinking of emotion health for fun (1/6)
	Views of relationship between emotional issues and mental health (2/6)
Changes/taking actions (4/6)	Uncertainty of how to react to data (2/6)
	Doubt that data cannot change life (2/6)

initial categories	Codes
Accuracy (6/6)	Data (do not) matches the actual situation (4/6)
	Doubts about the accuracy of the data to define a state (4/6)
	Views on the Accuracy of Mental State Measurements (2/6)
	Doubts about the accuracy of the data to distinguish two state (5/6)
Needs / goals (6/6)	Suggestions for target status (2/6)
	Check if enter target state (4/6)
	Increasing interpretability: Reasoning (2/6)
	Target status: relax (1/6)
	Increasing interpretability: emotions (1/6)
	Interest of emotional problem (2/6)
	Stabilising stress (3/6)
	Remind of unconscious problem (4/6)
	Curiosity of physiological (scientific) reaction (2/6)
	Knowing data's impact (4/6)
	Prediction (2/6)
	Suggestion of how to deal with results (4/6)
Metric (6/6)	Uncertainty of the measurement of a metric (2/6)
	Ambiguity of the definition of a metric (5/6)
	Right state "concentrated" (3/6)
	Interest of stress (6/6)
	Interest of focus (3/6)
	Uncertainty about the relationship between stress and focus (1/6)
	Active status: engaging, efficiency (2/6)
	Uncertainty about the relationship between interest and excitement (2/6)
	Negative results from prolonged stress: Exhaustion (1/6)

Doubts and uncertainty about data

Although the discussions on "track functions" and "attitude" revealed that not everyone expects to make changes or take action based on the data, approximately four out of the six interviewees further pointed out that the difficulty lies in feeling that the data cannot help them make specific changes, or finding it difficult to achieve the improvement they envision.

"Also, if it claims to measure stress or something like that, I personally feel that I don't have the capability to adjust at the moment. Even if you know you're under a lot of stress, you can't just stop doing what you need to do..(S1)"

Questioning the accuracy of data results

Accuracy is a term that every interviewee mentioned, as it is indeed essential for data. However, each individual has slightly different

definitions of accuracy. Some people think about measurement accuracy, while others focus on the accuracy of the results. For the participants in this study, the accuracy of the results is what concerns them the most. Interestingly, when discussing only one type of data result, skepticism may not be as deep. However, when there are multiple data results, users tend to show greater doubts. They may question, "Why am I judged as A instead of B? What is the difference between A and B? Is it possible that I am both A and B?"

Need a moderator between users and the data

When discussing the requirements for data, interviewees raised various aspects of needs. The most frequently mentioned by participants (4/6) were "check if enter target state," "remind of unconscious problem," and "suggestion of how to deal with results." The commonality among these points is that users want more than just seeing data; they want the tracker to interact and communicate with them using the data, whether it's through reminders, suggestions, or assistance with relaxation. If the data remains just data, users may experience the issues described earlier of "doubts and uncertainty about data," where users don't know how to interpret and utilize the data.

9 Refined categories

In order to refine the codes further, codes originally assigned to the same categories are being reorganized. Similar codes are being merged to create new codes. Then, these codes have subsequently been defined into 9 refined categories (Table 2.3.3, details see appendix B).

Table 2.3.3. *Overview of nine categories*

Refined Categories
Biased understanding on MWL
Limited explanatory space
The confused classifications of MWL from user perspective
Different levels of data within a tracker
Incorrect information at incorrect timing
Long-term and short-term impact of motivation
Indifferent and distrust
Different ways to help different users
Work-centric self-tracking

Second layer insights: based on descriptions of initial categories

Biased understanding on MWL

Regarding the definition of MWL, although from the previous section we mentioned that most people perceive MWL as being closely related to stress, apart from stress, some people also believe it may be related to emotions or cognition. Contrasting the definition of MWL with the explanations of mental load and cognition load provided by the interviewees, it is evident that most people interpret MWL from the perspective of mental load, overlooking the influence of cognition load.

Limited explanatory space

In terms of limitations of explanatory space , we found discrepancies in the ability of interviewees to explain emotions and cognition. Emotions are a familiar yet difficult-to-describe domain for people, often ending with a single adjective and proving challenging to quantify or compare. On the other hand, cognition is more easily articulated by individuals, as well as quantified. For instance, factors such as work efficiency, workload, and the extent of cognitive effort required are easier to describe and quantify. These descriptions typically lack emotional components and resemble statements of fact.

The confused classifications of MWL from user perspective

In the preceding sections, we mentioned the difficulty users face in defining or explaining certain concepts, such as categorizing MWL and describing the ideal MWL state. Interview results indicate that respondents often use "activities" to explain different levels of MWL. This suggests that various activities have preset MWL levels in users' minds, sometimes explained from the perspective of mental load and other times from the perspective of cognition load. Overall, there may be a default MWL classification system in people's minds, but the classification methods are often confused and ambiguous.

Different levels of data within a tracker

If we classify the functionalities described by the interviewees regarding the tracker according to Rowley's DIKW pyramid (2007), some functionalities such as behavior record and verify are considered information to users. For example, tracking the number of steps taken in a week or monitoring sleep duration of at least six hours are structured data that directly provide users with simple information such as "who, what, how, when." Knowledge, on the other hand, involves the analysis and interpretation of information, offering explanations for "how and why," which aligns with the interviewees' descriptions of quality scores and reminders. Adjustment, leaning more towards Wisdom, entails providing information for decision-making and actions based on an understanding of the data.

Long-term and short-term impact of motivation

The motivations for using a tracker can generally be divided into two categories: long-term and short-term impacts. Long-term motivations typically involve specific goals such as exploring the root causes of negative stress, maintaining control over daily life, improving health, or enhancing work efficiency. These motivations usually have a lasting impact on users. On the other hand, short-term motivations are more transient and may include seeking a sense of achievement, novelty, fun experiences, or feeling secure in verifying data in the moment.

Incorrect information at incorrect timing

As highlighted in the previous paragraph where users highly value the timing of reflection. It's evident that tracking data and using data occur at different times and serve different purposes for users. For example, tracking data is for understanding one's work performance, while using data is for improving work performance without disrupting tasks. If the timing for the latter is incorrect, it can lead to a negative user experience, such as data use during tasks causing interference. Therefore, offering accurate information at the appropriate timing is essential.

Indifferent and distrust

From the overall interview results, users can generally be categorized into two attitudes: those who are indifferent to data and those who distrust data. The most significant difference between the two lies in the fact that individuals who are indifferent to data, such as passive users or overly confident individuals, have low demands regarding data. On the other hand, those who distrust data may develop a skeptical attitude because the data fails to meet their needs. For instance, the data may not provide them with new insights or help improve their situation.

Different ways to help different users

From the perspectives of the interviewees regarding their data needs, although they all express a desire for data to be more than just data, these needs can generally be categorized into two types: suggestions and direct assistance. Firstly, the target state serves as a form of suggestion. It represents the suggested state given to users based on system analysis. Regardless of whether these suggestions are easily understood, users primarily seek to gain new information and insights from them. On the other hand, assistance is more direct. For example, users may wish for reminders or confirmation features from the app, or they may hope for assistance in relieving stress when it is detected. Suggestions and assistance represent different levels of needs and result in varying degrees of intervention in users' lives.

Work-centric self-tracking

Tracking primarily revolves around work, whether it's examining data, graphs, or metrics. Interestingly, participants' discussions often center around their jobs. What's noteworthy is that for most people, the distinction in life is between holidays and workdays, or between uncompleted goals and completed goals. Work serves as the focal point for the majority of individuals, representing a goal that requires continuous improvement and tracking. However, once work hours are over, even though daily life may not be perfect, people often lack the motivation and need to track and improve their daily lives.

Narrative frame and 5 Themes

The difference between thematic analysis and other qualitative analyses lies not only in summarizing insights grouped under the same category but also in developing a user-centered narrative to understand their values and perspectives on a matter. The purpose of summarizing the preceding chapters' categories is to generate significant themes and weave them into a story.

The narrative framework is depicted in Fig 2.3.3, which consolidates all categories mentioned in the preceding paragraph into a cohesive storyline. Subsequently, building upon this storyline, five themes are elaborated upon in the following paragraph.

Enhance the connection

"Users' motivations and needs are straightforward, and their memory points for a product or technology are simple. Therefore, understanding the core needs of users is crucial, as different motivations require varying levels of information. However, concerning the attitude of users towards self-tracking MWL, short-term impacts and motivations may not support them in sustaining the use of this product or behavior. This is because some users' indifferent attitudes suggest that understanding their MWL is optional for them. Therefore, it is essential to strengthen the importance of tracking MWL and its relevance and impact on users."

Not merely about stress

This research had identified two main types of attitudes among users: indifference and distrust. The indifferent attitude may be influenced by various factors, as users subjectively perceive the limited capabilities of data or lack of novel information that the data can provide, leading them to adopt an indifferent attitude both before and during usage. A typical description from users of this type regarding tracking MWL might be, 'I believe I can track my stress through this app, but that's all about it, nothing more.' However, in reality, stress is not the only outcome of measuring MWL, and users miss out further insights into cognitive capacity balance, thus limiting their expectations of this technology. Therefore, it is crucial to break free from the stereotype of 'it is just about stress' associated with such products.

More than data

From the analyses, trackers not only provide information, but also play the role of a communication bridge between users and data. Because of the negative or passive attitude of users towards understanding cognitive data, it is difficult for low-level information to satisfy users' motivation and demand for tracking MWL. People's overconfidence in their own knowledge may also be one of the reasons that prevent users from taking a positive view of cognitive data, as this "factual level" of information is perceived as something they already know. What else can a tracker do besides presenting data? There were a number of suggestions from interviewees during the interviews, and although the ways in which people want help may vary, as discussed earlier, the concept of 'making data more than just data' is an important thing in guiding users to follow MWL.

Resonating with the cognitive data

For both “indifferent” and “distrust” users, research indicates a low resonance with the data. This could be attributed to information factors, as the data may not be well-designed or translated properly, or to human factors, as people instinctively find it difficult to believe that cognitive status can be quantified and improved. If users' demands for tracker functionality only remain at the information level, perhaps the acknowledgment of cognitive data issues is not significant. However, if users seek information beyond the knowledge level, without first convincing users to acknowledge cognitive data, it becomes challenging to persuade them to trust the device's judgments and recommendations. It's a kind of vicious cycle, where people both need deeper analysis to believe in the technology but fundamentally doubt the data from this technology. To address this issue, strengthening resonance between users and cognitive data is crucial.

Providing right information at right times

The timing of usage is another influencing factor on the overall tracking results. Regardless of the user's attitude, if the data intervenes in the user's life at the wrong time, it can lead to negative outcomes. The analysis results indicate that the primary motivation for MWL tracking users is to enhance work performance rather than improve trivial aspects of daily life. This reflects the human tendency to differentiate things between 'needs constant improvement' and 'does not need special improvement,' which should be taken into account when considering the timing of using trackers. Reflecting on timing , on the other hand, requires considering the work context and designing different time points and different levels of information for user-device interactions under the premise of not disrupting work.

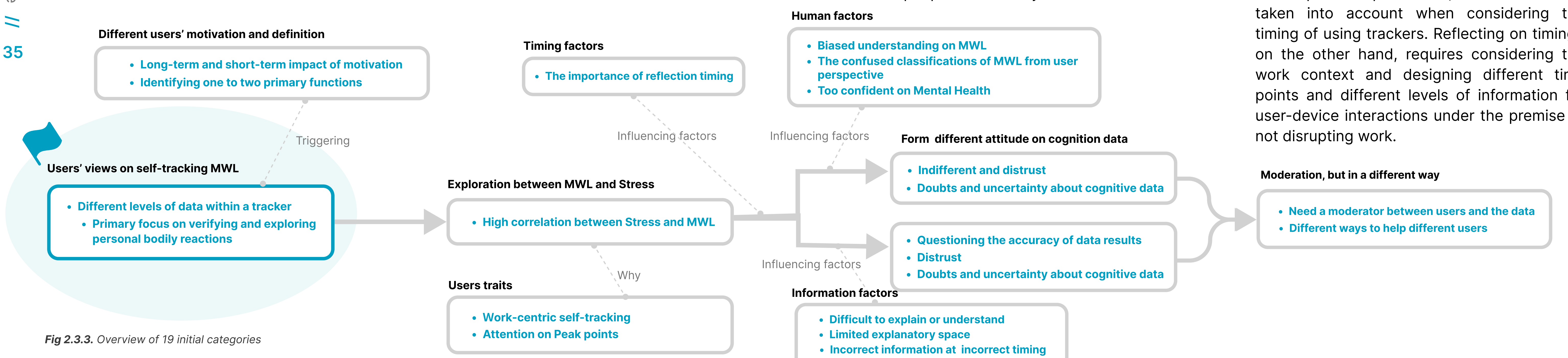


Fig 2.3.3. Overview of 19 initial categories

2.4
Conclusion of exploratory interview

Takeaways from literature

- Whether through traditional measurement methods or tracking cognitive data via wearable devices with Neurotechnology, the results often lean towards depicting Workload rather than MWL. This is because current measurements typically indicates the "current cognitive status" rather than assessing whether the current cognitive status aligns with the cognitive demands.
- There are various understandings of WL and MWL among individuals.
- The measurement of MWL is subjective ,compared to measuring workload, as it may be influenced by different contextual factors, which are usually uncontroallable and unpredictable.
- Utilizing Li et al. (2010)'s five-stage personal informatic self-tracking model helps explore user behavior and needs from different stages and identify areas where need further user research.

Takeaways from Interview

- As people's acceptance and understanding of tracking cognitive data remain limited, there is a need to dive deeper into how the data is presented.
- Users should not be constrained by their understanding of "stress" but should instead be able to comprehend the relationship and mutual influence between cognitive data and daily life.
- Users should perceive that they can gain new insights from the data and that the tracking process holds reflective value.
- Considering providing users with appropriate information and functionality at different time points are another key focus in designing cognitive data trackers.
- Making people acknowledge cognitive data may be a challenge.

To the next step

In conclude, the insights from these studies will be translated into design ideation for user testing in the next step.

The defined five themes would be further discussed in the next chapter.

- **Enhance the connection**
- **Not merely about stress**
- **Resonating with the cognitive data**
- **More than data**
- **Providing right information at right times**

Chapter 03

From research to design verification

3.0

This chapter mainly explores how the research findings from Chapter 2 can be addressed through design. It involves reviewing literature to identify potential solutions to various issues, and ultimately planning the design validation stage and methods.

3.1 From research to design solution

3.2 Related work

3.3 Conclusion: From solutions to design verification

3.1 From research to design solution

Following on from the research insights in chapter two, there are five main directions that can be explored further. From these five main research insights, this chapter considers how to achieve these goals in design. Several involved questions are listed as a starting point. After that, each issues are be discussed through literature review to find out potential solutions. See Fig 3.1.1.

From Chapter 2 ▼ | See the following paragraph ▲

Research insights	Involved Question	Potential Solutions
Stress, but not merely stress	▸ What is the relationship between stress and MWL?	• Refer to literature review on stress to differentiate it from MWL
Enhance the connection	▸ What can be linked with MWL? ▸ How does tracking MWL affect a person's life?	• Refer to literature review on how MWL impacts our life
Resonating with the cognitive data	▸ Why don't people identify/resonate with cognitive data?	• Refer to literature review on user perception on data accuracy
More than data	▸ Other than merely displaying data, What other forms can data be converted into? ▸ What kinds of interaction can be built between data and users?	• Refer to literature review on interactive personal informatic data design
Providing right information at right times	▸ How to prevent negative experience, like distracting, at certain use moment?	• Refer to literature review on how to Reduce burden of absorbing information • Refer to literature review on reflective data design

Fig 3.1.1. *Thinking Process from Research to Design*

3.2
Related work

Differentiate stress from MWL

Building upon the discussions in Chapter Two, the research finds that users' understanding of MWL largely centred around stress. However, stress is a broad term for people, making it difficult to provide specific and objective descriptions. How is stress formed? Why do people associate it with MWL? This study attempts to trace clues from theories related to psychological stress and focuses on how we can design to enable users to see knowledge beyond "stress" from MWL cognitive data.

Similarity between stress and MWL

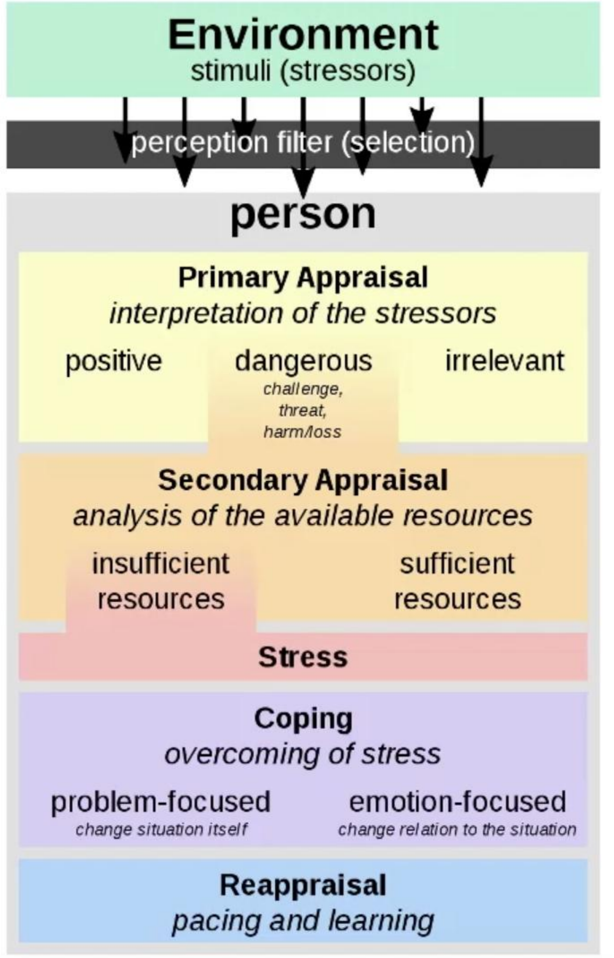
According to Lazarus et al (1984)'s stress theory, stress is conceptualized as a perceived imbalance between demands and resources. As illustrated in Figure 3.2.1, stress is triggered by the imbalance demand from the environment, prompting individuals to interpret and analyze the situation to judge its susceptibility, severity, and assess available resources. The evaluation points people assess during the formation of stress are remarkably similar to what is discussed in MWL theory, both focusing on whether demands and resources achieve balance. As a results, their occurrence can be concomitant.

However, according to Hidalgo-Muñoz et al. (2018), MWL and stress can be reasonably viewed as distinct phenomena. Gaillard (1993) suggests that individuals can exert considerable effort on difficult and complex tasks even under adverse conditions without experiencing cognitive tension or adverse physiological effects. In contrast, Gaillard views mental stress as a state characterized by inefficient cognitive resource allocation and susceptibility to negative emotional interference. In other words, high cognitive load does not necessarily result in high levels of stress, and high levels of stress can also occur when cognitive load is low.

Therefore, stress can be seen as individuals' intense negative emotional response to adverse MWL, or as a warning sign of poor cognitive resource allocation.

Coping strategies with stress

After clarifying the differences between stress and MWL, adjusting stress remains a user expectation. According to Lazarus et al (1984)'s stress theory, it is noteworthy that regardless of secondary appraisal, coping effort, or outcome, emotions are separately identified. This points out that emotions may serve as both inputs and outputs in the stress formation process, interacting with stress mutually. When coping with stress, there are two possibilities: solving problem itself or adjust the emotion (the relation to stress) (Lazarus et al., 1984). This model predicts that for modifiable stressors, problem-focused coping strategies are most adaptive, whereas **for unchangeable or uncontrollable stressors, emotion-focused strategies are most adaptive**.



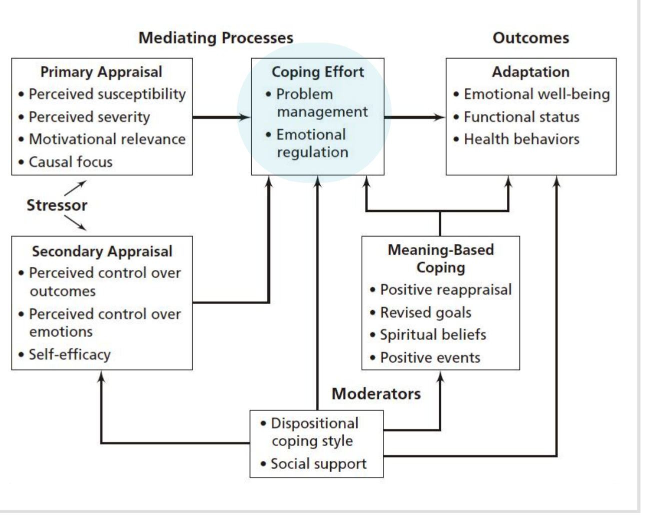


Fig 3.2.1. Lazarus et al (1984)'s stress theory

Impact of tracking MWL

Next, the focus of this section lies in how, beyond the familiar concept of stress, we can present the concept of MWL and how tracking MWL can impact our lives.

Each level of MWL means a lot

Midha et al. (2022) invited many individuals to categorize MWL into three levels: high, medium, and low. They pointed out that (1) people may experience positive or negative emotions at both high and low MWL levels, with experiences at a medium MWL level being optimal, often referred to as a "happy medium." (2) Each level of MWL carries its own significance; for instance, High MWL is associated with high-intensity work, work quality, and a sense of achievement, while Low MWL is associated with rest, recovery, and reward. Medium MWL is linked to productivity and positive perception. Each level of MWL represents unique activities and experiences, and there is no standard of good or bad level of MWL.

Sustainment is an issues indeed

In the study by Midha et al. (2022), it is noted that prolonged maintenance at the same level of MWL is commonly believed to have negative effects on our lives. For instance, extended periods of high MWL may lead to issues such as burnout and fatigue, while prolonged periods of low MWL may result in decreased enjoyment or feelings of boredom. Even when sustaining a "happy medium" over the long term, happiness may diminish. (See Fig 3.2.2) It seems any kind of positive experience will be damaged by long period of "time".

The Importance of Transitioning States and the Difficulty of Achieving an Ideal State

As a result, the concept of the "Mental Workload Cycle," was proposed (Midha et al., 2022), suggesting that individuals naturally fluctuate between different levels of MWL, which the authors view as beneficial. However, the study also pointed out the difficulty in transitioning between states and entering states, which can be influenced by external contextual factors, internal factors, life factors, and so forth.

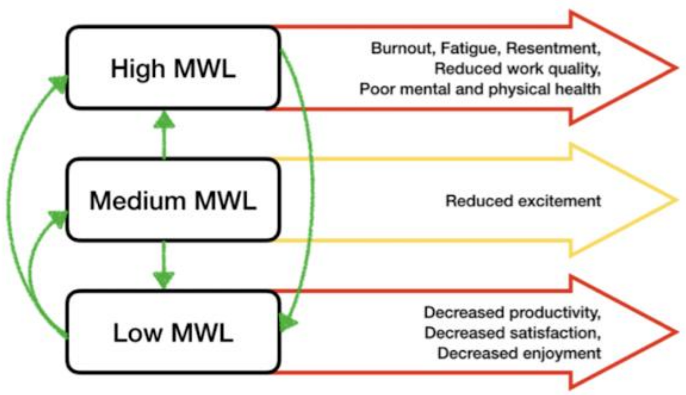


Fig 3.2.2. *The negative effect of sustaining each level for too long (Bagheri et al., 2020)*

This research highlights the application of MWL theory in human life and the resultant impact of MWL, which can be considered while designing MWL data.

User's perception on "accuracy"

However, in everyday life, it is challenging to accurately categorize situations into high, medium, and low MWL. Especially as indicated in the literature review in section 2.1, MWL itself is a subjective concept. When individuals find it difficult to assess the accuracy of information provided by a system, it can lead to a sense of distrust (Yang et al., 2015, September). Although usability issues have been pointed out by Mackinlay (2013) as problems where users find it difficult to verify data accuracy, understanding users' perception of "accuracy" before verifying data is also essential.

Achievable goal: "consistent"

Although people generally use "accuracy" to describe the correctness of data, in statistics, there are other terms that describe similar concepts: "Trueness" and "precision." These three terms have clear differences in their definitions. (Fig 3.2.3~3.2.5)

- ***Accuracy*** *refers to "the closeness of agreement between a test result and the accepted reference value (British Standards Institution (BSI), 1994). "*

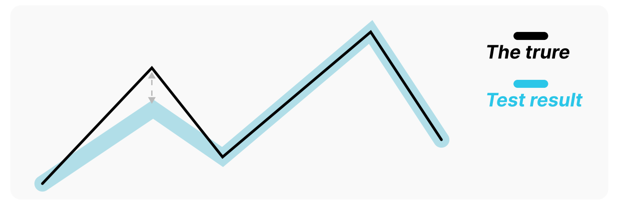


Fig 3.2.3. *Demonstration of Accuracy*

- ***Trueness*** *refers to "the closeness of agreement between the average value of a large number of test results and the true or accepted reference value (British Standards Institution ,BSI, 1994). "*

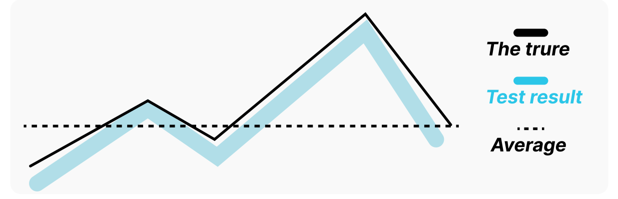


Fig 3.2.4. *Demonstration of Trueness*

- ***Precision*** refers to the closeness of agreement between test results and "does not relate to the true value or the specified value *(British Standards Institution (BSI), 1994). "*

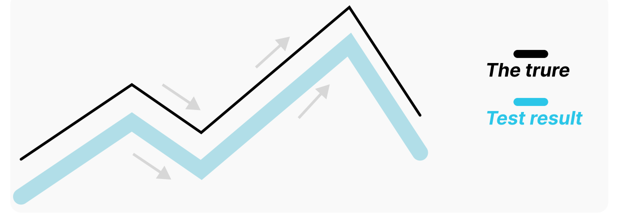


Fig 3.2.5. *Demonstration of Precision*

Research (Yang et al., 2015, September) suggests that regardless of the type of data, "Accuracy" remains an important goal. However, for continuous data, such as a line chart, precision is more important than trueness. This is because for users, as long as they can observe continuous changes and the correct trend, the data is consistent and trustworthy. Compared to pursuing accuracy, this is a more achievable goal.

Improving measurability, allowing user calibration, and increasing transparency

As Gulotta et al. (2016, June) emphasized the importance of maintaining the system, they suggests that improving measurability, allowing user calibration, and increasing transparency can help enhance user trust in tracking devices. Firstly, when data is consistent but still inaccurate, it may be due to systemic errors. Such issues can be corrected through calibration. Secondly, curiosity about the accuracy and reliability of data often drives users to evaluate the device's accuracy and reliability through various small tests. Assisting users in conducting simple tests can actually help increase their trust in the data. Furthermore, a common issue for users is the difficulty in understanding the calculation principles behind system indicators. However, once they understand the process of indicator generation, users become more tolerant of inaccuracies because they understand the reasons for the limitations.

Interactive personal informatic design

From the literature review in the previous section, we learned that when the system's accuracy inevitably deviates from the ideal, aligning the system with users' tracking goals is another approach.

Personalization stimulates desired interaction between users and system

Gulotta et al. (2016, June) suggests that promoting interaction between users and the PI system helps users achieve personal goals. However, individuals' goals may change over time (Schwanda et al., 2011, May). Therefore, provide personalized features can effectively stimulate reflection and periodic introspection. According to the definition of personalization in PI system, it also involves allowing users to customize the functionalities they desire to interact with the system (Blom et al., 2003). Such interactions typically yield positive outcomes as they reduce users' cognitive load.

Through less intrusive interactions

However, in creating user-system interactions, to alleviate the burden of learning and usage for users, literature suggests that ambient information design can be employed to prevent users from giving too much attention (Chatzitsakyris et al., 2004, April). The design direction of ambient information can focus on reducing interaction time, facilitating insights generation, conveying the essence of data, and aiding in building data-related knowledge (Stasko, 2014, November). For example, extracting appropriate metaphors from nature to convey the essence of data, such as representing heartbeats with the sound of water.

Reduce burden of absorbing information

In addition to leveraging techniques like ambient information design to reduce user cognitive burden, another approach is to focus on data design itself.

Levels of abstraction

Bentvelzen et al. (2023) categorized data into three levels of abstraction: high, medium, and low. Levels of abstraction refer to how detailed or complex data is presented. As depicted in Fig 3.2.6

In addition to leveraging techniques like ambient information design to reduce user cognitive burden, another approach is to focus on data design itself.

- **High level of abstraction**: Data is represented in a generalized or summarized form, providing an overview or big-picture perspective.
- **Medium level of abstraction**: This level provides a moderate level of detail, offering more specific information compared to the high level but still maintaining some level of generality.
- **Low level of abstraction**: At the lowest level, data is represented in its most detailed and granular form. This level contains raw or unprocessed data, offering the most specific and detailed insights.

Medium level contributes to reflection

Research suggests that moderate levels of abstraction can evoke the best reflection. Compared to data designs with the lowest abstraction levels, those with moderate levels perform best in terms of transparency and reflectiveness. This implies that providing more detailed information doesn't necessarily lead to more meaningful reflection. Overall, excessive information may not help users understand, while insufficient information can lead to ambiguity in understanding. Designing data or indicators with a moderate level of abstraction can effectively promote user reflection and can be a key consideration in data design.

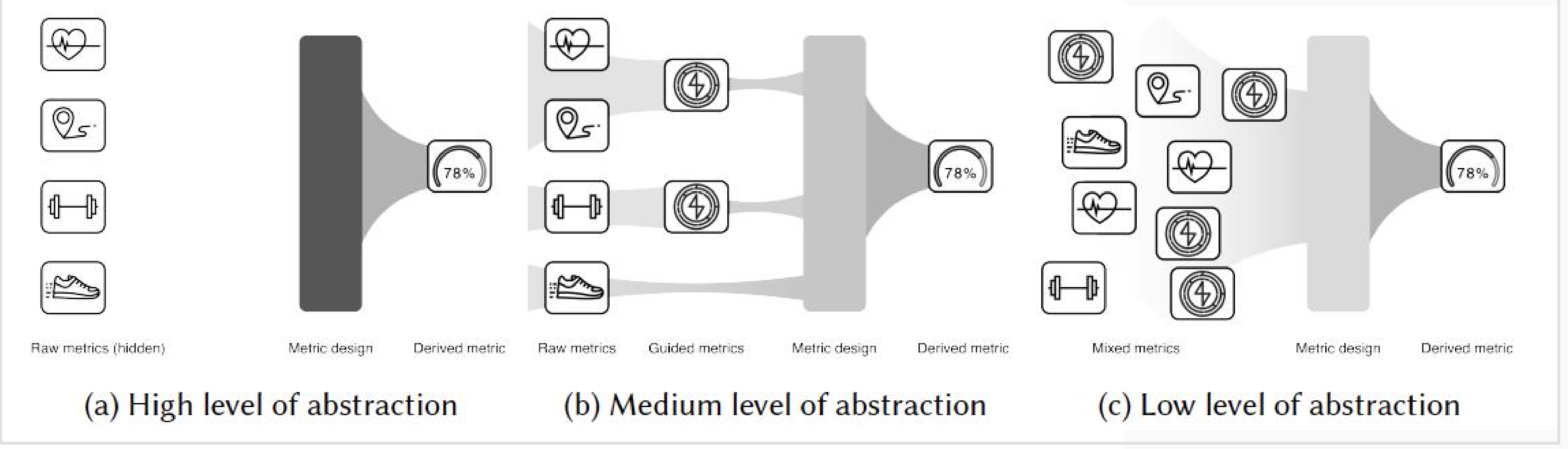


Fig 3.2.6. Demonstration of three different levels of abstraction, (Bentvelzen et al., 2023)

3.3 Conclusion: From solutions to design verification

Takeaways from literature

- Stress is **intense negative** response to MWL.
- Stress is kind of **warning sign** of poor cognitive resource allocation.
- To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive.**
- **No judgement** on MWL's performance.
- **Sustainment** may be a big issues when measuring MWL.
- **Entering another status** may be a target for users.
- To help resonate more with data for accuracy issues,
    - If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users.
    - Allowing the user to **calibrate data or set their own objective may help.**
    - Allowing **Testability**.
- To help build more interaction with data,
    - Allowing the user to **build up a personalized historical data**
    - Using **Metaphorical abstraction** to stimulate reflection in the user
- **Segmenting information** to reduce users' burden.
- Different levels of **data abstraction** stimulate different levels of reflection. It is not necessary to show the data in great detail.

Up to this point, this research obtained many insights and expectations from users and literature review about this technology in the previous chapters, as shown in Table 3.3.1

Table 3.3.1. *Interview Questions*

User Issues from Chapter 2	Insights from literature review
Stress, but not merely stress: value stress but interpret it well with MWL	• Stress is kind of **intense negative** response to MWL • Stress is kind of **warning sign** of poor cognitive resource allocation • To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive**
Enhance the connection: emphasize data's impact on people's lfe	• **No judgement** on MWL's performance • **Sustainment** is the main issues • **Entering another status** can be a difficulty
Resonating with the cognitive data: build users' trust on data	• If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users • Allowing the user to **calibrate data or set their own objective** • Support for Testability
More than data: help users develop understanding or interacting with data in a different way	• Allowing the user to **build up a personalized historical data** • Using **Metaphorical abstraction** to stimulate reflection in the user
Providing right information at right times: reduce negative experience	• **Segmenting information** to reduce users' burden • Different levels of **data abstraction** stimulate different levels of reflection

To the next step

The next step will focus on verifying research insights generated in this chapter. However, since such products are not yet widespread, users may have insufficient understanding or lack motivation to use them. In addition, due to concerns about data accuracy (mentioned in chapter 1.5), this research adopts co-design instead of usability test to conduct design verification.

Co-design

Co-design was initially proposed in the 1970s by Scandinavian unions and is a design method that involves stakeholders in the design process. Co-design emphasizes the design process rather than the outcome and values user participation in design. Sanders et al. (2008) depicted the "new landscapes of design" (Fig 3.1.1). The horizontal axis distinguishes the role of users in the design process, while the vertical axis distinguishes between design-led and research-led approaches. As depicted in Fig 3.1.1, Participatory design (co-design) and Scandinavian, as a design method led by research and treating users as partners, is situated in the lower right corner of the coordinate system, which aligns well with the methodological requirements of this study.

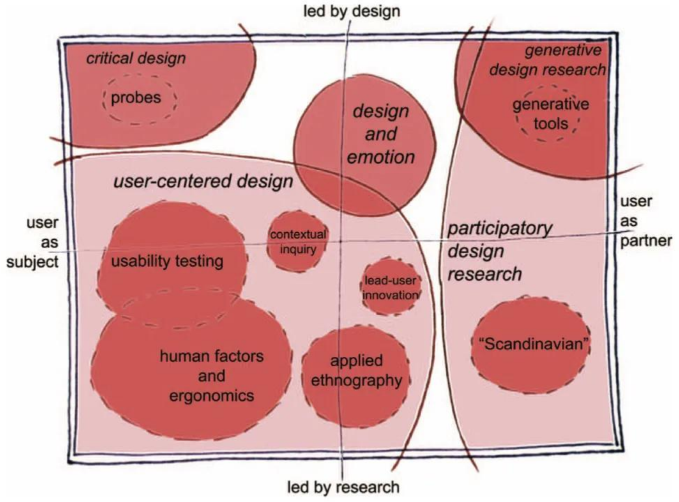


Fig 3.1.1. *new landscapes of design, (Sanders et al., 2008)*

User test & Survey

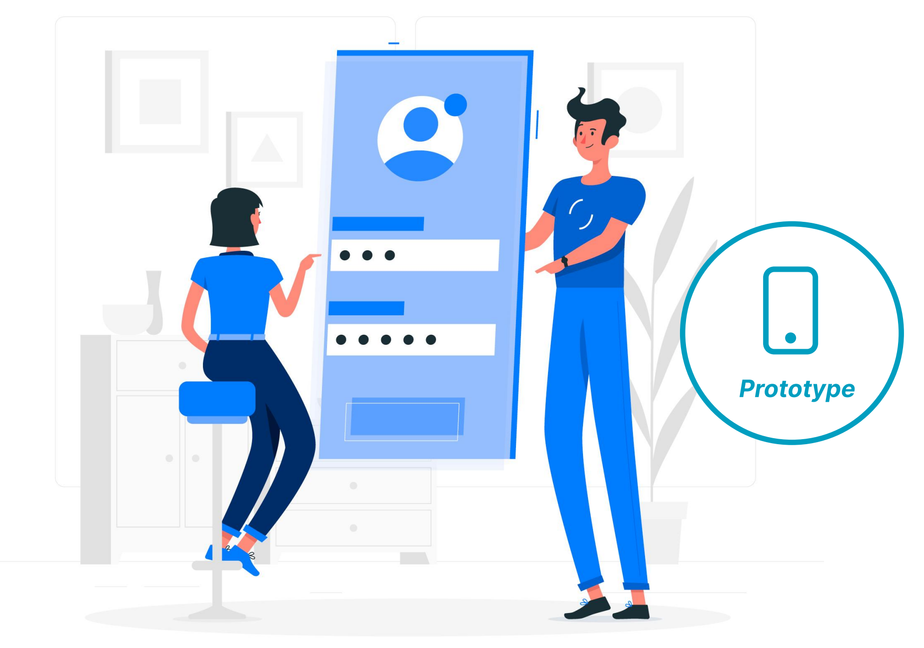
However, as the interviewees did not actually use the product to track MWL. There is a possibility that their thoughts may change after actual usage. Therefore, conducting design verification would be helpful for future research and design.

Because the technology is not yet mature, design will not be the main focus of this study. Instead, the design process will be primarily led my research (according to the insights from chapter two) to speculate on how future designs can better meet user needs. Throughout the co-design process, users will act as partners to:

1. **Use rapid prototypes created in this research as tools to verify and discuss usage needs and design suggestions.**

2. **Share their ways of cognitive data recording**

There is no predetermined sequence for these two activities. The main difference lies in exchanging ideas between both sides (users and designers) regarding the presentation of MWL data. The former activity involves booklet design, while the latter involves prototype design. The process and results of the former activity will be described in Chapter Four, while the results of the booklet will be discussed in Chapter Five.



User Test

See results in Chapter Four

Co-designers will go through the design made by this research with the researcher and exchange their thoughts

Survey

See results in Chapter Five

Co-designers will share their ways of data recording through an offline survey booklet

Chapter 04

Co design: User test

4.0

In this chapter, a rapid design was developed based on insights gathered from previous research and was employed in the user test. The objective of this user test is to explore users' needs rather than focusing on usability. Participants are viewed as co-designers, encouraged to share their genuine feedback and needs. Through the user tests, practical operations and experiences were observed, discussed, and analyzed.

4.1 Research Methodology: User test

4.2 Prototype Design

4.3 User Test Results

4.4 Conclusion of User Test

4.1 Research Methodology: User test

Purpose of user test

The purpose of this user test is to verify the insights gained during the research stage of this study, including tracking motivations, tracking timings, user needs, pains and so forth. Based on the conclusions from Chapters 2 and 3, this study translates user needs into design and generates **rapid prototypes as the tool of the test**.

In addition to validating the insights of Phase I, practical experience is a major emphasis of Phase II. This chapter will utilize it to explore the collection stage as described by Li et al. (2010)'s model, such as how users actually use this device and when users would want to use the data.

Research Procedure

During the test, each participant will be wearing a device that monitors their cognitive data. Simultaneously, they'll be asked to complete revised TSST test, which take approximately 13 minutes in total. After tasks, interview and card sorting are conducted for around 30 minutes. The whole process is shown in Figure 4.1.1.

Methodology

Tasks, sser testing with prototype, semi-structured interview and card sorting were conducted during the one-to-one on-site user test.

1. Tasks: TSST test

Tasks are designed to simulate stressed scenario. Refer the Trier Social Stress Test (TSST test) (Kirschbaum et al., 1993), participants will go through 3 minute preparation (for speech), 5 minute speech and 5 minute mental arithmetic to induce stress. The primary purpose of these tasks is to induce stress changes in users while they are using cognitive data, instead of focusing on users' physiological responses under stress. To make the scenario more lifelike, the second task is adjusted to record an motivation video for a job application. Compared to the original TSST test experimental design, this study gives participants more control over the process.

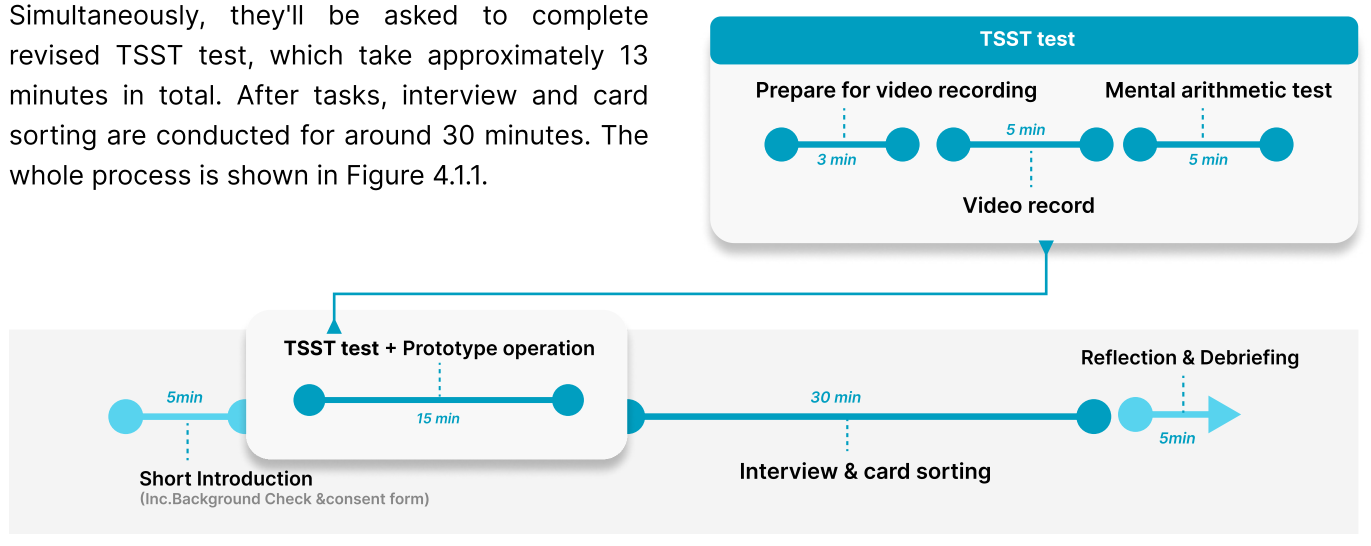


Fig 4.1.1. Card sorting tools

2. User testing & Observation

To stimulate users' thoughts, a prototype is designed, and the details of prototype design can be found in Chapter 4.2. During the tasks, participants can always use prototype to check their cognitive data. Observations will be conducted during the prototype operation.

3. Semi-structured interview

After tasks, one-to-one on-site semi-structured interviews are conducted.

The discussion involves their **experiences of wearing the device for the first time**, **the timing of using the data**, and **their understanding of the current design**. The final discussion involves using card sorting to explore the importance of different functions and elements to the user.

4. Card sorting

After interviews, card sorting method was used to understand how users perceived the existing functions within the app and what they deemed to be priority functions. Participants were given a predetermined set of categories: **must-have, nice-to-have and unnecessary (see Appendix B).** They were asked to organize different features into these categories based on their personal experience.

Recruitment

Ten participants were recruited in total and through snowball sampling in TUDelft campus. As a result, all participants are students background. Similar to interview recruitment, the research didn't require any specific background as everyone could be the users of Neurotechnology device. In total, there are five males and five females participating in this test, with ages ranging between 20 and 30 years old.

Setup

During the task setup, as shown in Fig 4.1.2, the researcher and participant will sit at the corner of the table with a certain distance between them. In front of the participant, there will be a tablet, blank paper, and a pen for task use. The prototype (iPhone) will be placed next to the tablet for convenient access. The participant will wear EMOTIV headphones throughout the study.

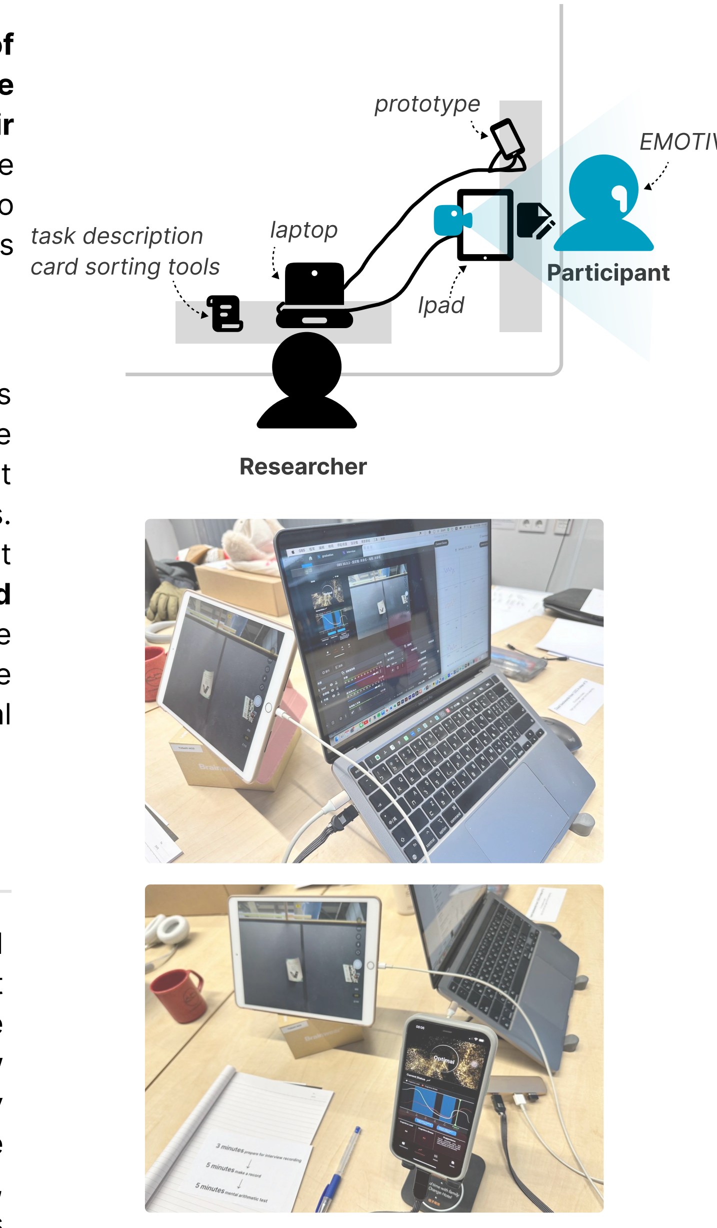


Fig 4.1.2. Setup of user test

4.2
Prototype Design

A rapid prototype design was generated, resulting in four main page and functions.

Limitation

Referring back to the project limitation mentioned in chapter 1.5, an existing product will be selected as the reference of this research and to support the design of the prototype.

Among the various options available in the market, EMOTIV (Fig 4.2.1.) has been chosen as the tool to aid in this research. The reasons and traits of this product will be explained in the next page.

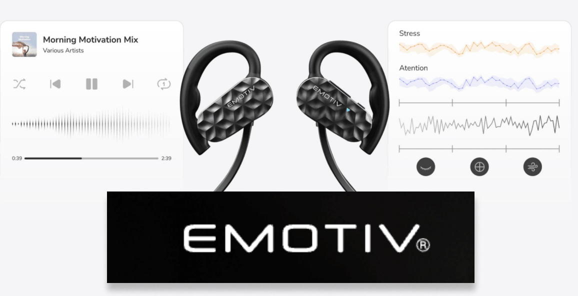


Fig 4.2.1 *EMOTIV's application*

As a result, the following paragraph will explain:

4.2.1 How this research extends its design from the elements, data, and metrics of the existing EMOTIV product to form four main functions

4.2.2 Which research results the design originated from

4.2.3 The detailed design of the prototype

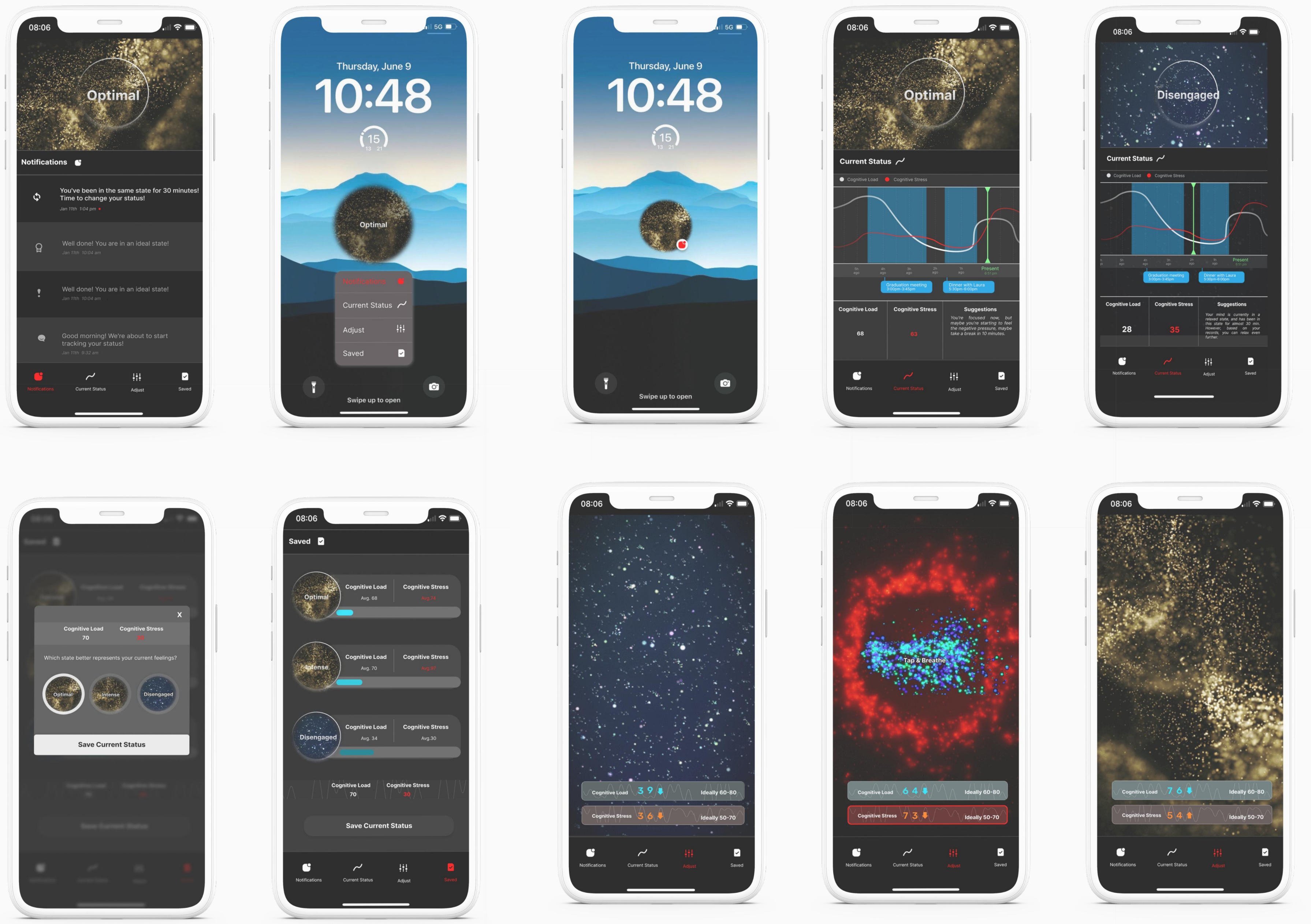


Fig 4.2.2. *Overivew of the prototype*

4.2.1 Extends the design from the raw metric and derived metric of the existing EMOTIV product

To explore the relationship between stress and MWL, this study selected a product equipped with stress indicator: **EMOTIV MN8** and analyzed its data and design as the reference.

In general, EMOTIV MN8 is an innovative brain-machine interface device that combines brainwave monitoring technology with the portability of headphones. It utilizes dual-channel electroencephalogram (EEG) technology to accurately monitor brain activity. It has developed both desktop and mobile applications. Two types of metrics are the main information generated from this product: “performance metric” and “cognitive efficiency”. “Cognitive efficiency” is generated based on performance metrics.

Performance metrics

There are three performance metrics: Attention, Cognitive Stress, and Cognitive Load. **Attention** measures the focus while performing a single task. **Cognitive Load** refers to the amount of cognitive resources needed by a person when performing a specific task. **Cognitive Stress** refers to the pressure or perception of cognitive load under a task.

There are two presentation formats: one is a line graph (only viewable on the computer software), and the other is numerical percentages (displayed on the mobile app) (Fig 4.2.3).

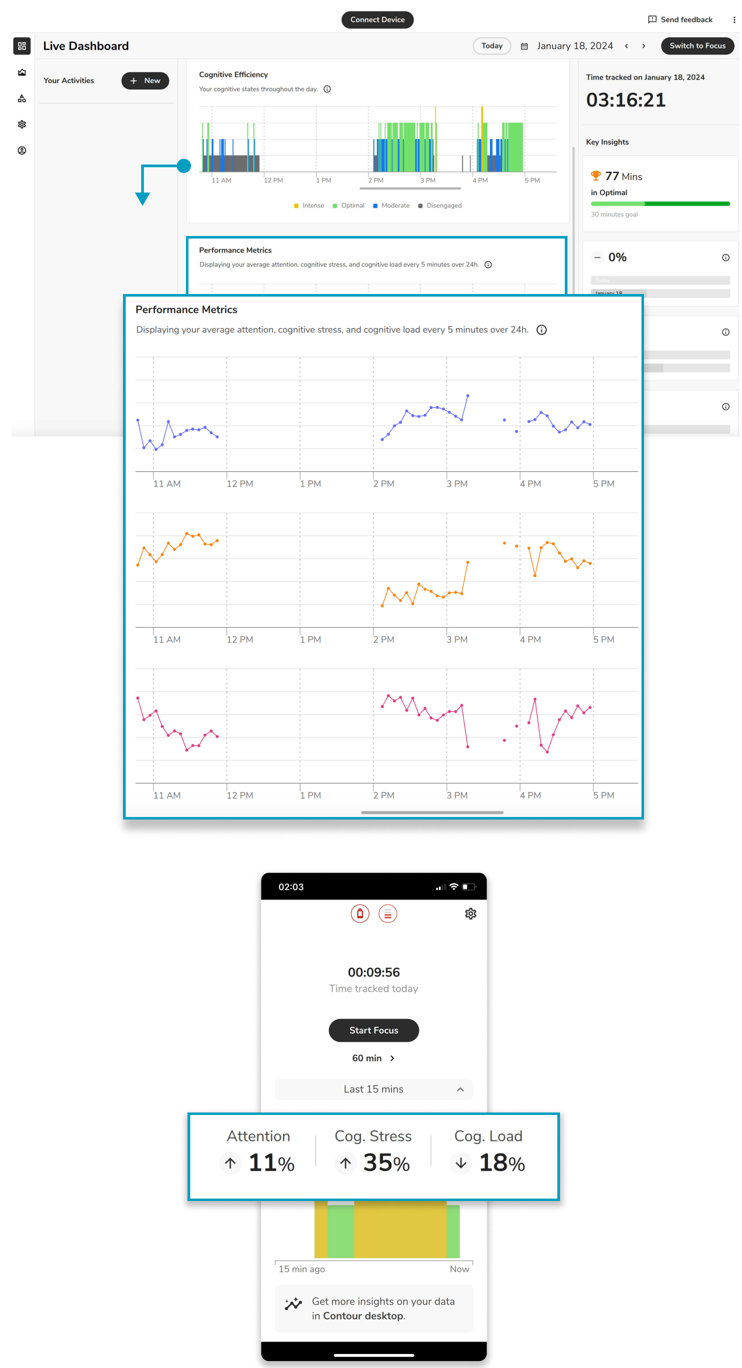


Fig 4.2.3. *Placement of performance metrics on desltop and mobile version*

Cognitive efficiency

For Cognitive Efficiency, EMOTIV has developed four metrics to represent different levels of Cognitive Efficiency. These four metrics are generated based on performance metrics.

- **Intense**: Indicates that the user is in a state of overload and the level of stress is very high. Prolonged exposure to this state can lead to fatigue.
- **Optimal**: This state represents the optimal balance of cognitive stress, cognitive load, and attention for the user during this period, making it the ideal state for work.
- **Moderate**: Indicates that the user is fluctuating between being focused and unfocused, and is prone to distractions at any moment.
- **Disengaged**: Indicates that the user is not interested in the current activity and is unable to focus or engage in the work at hand.

These four cognitive efficiency metrics are the core information of this product, visualized through four colors of circular light spheres (Fig 4.2.4) serving as the primary information on the mobile interface. The information is also presented through bar chart in both the desktop and mobile interfaces.(Fig 4.2.5)

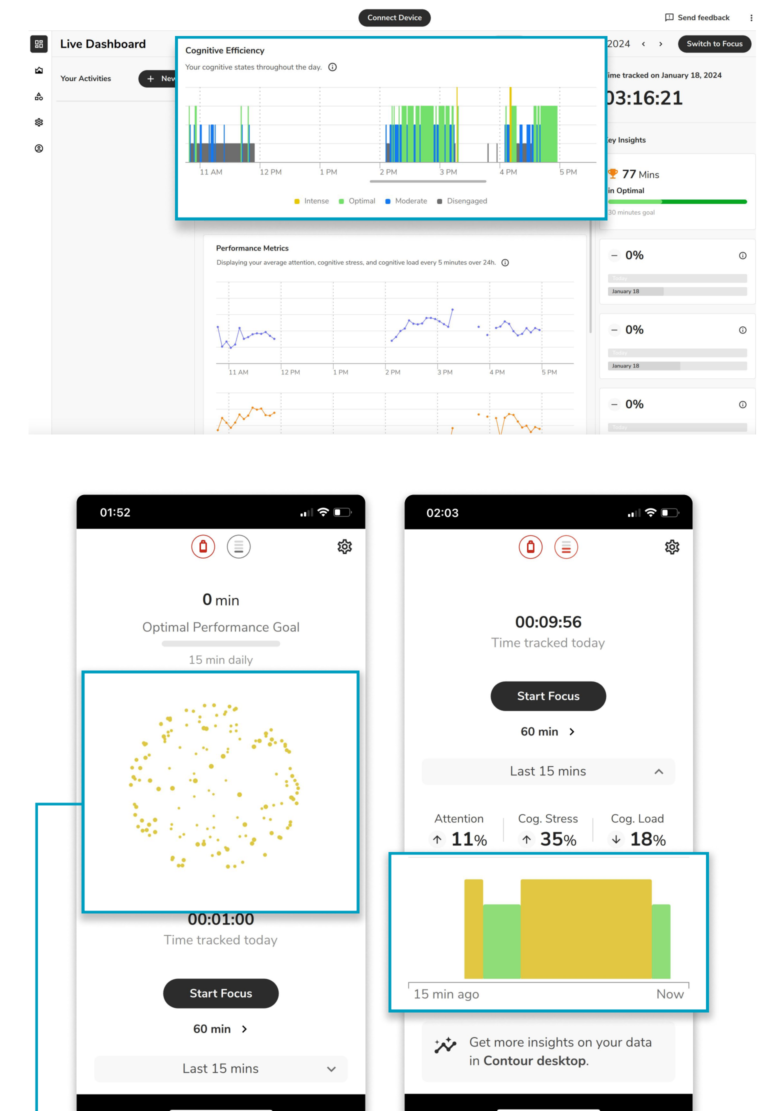


Fig 4.2.5. *Placement of four cognitive efficiency metrics on desktop and mobile version*

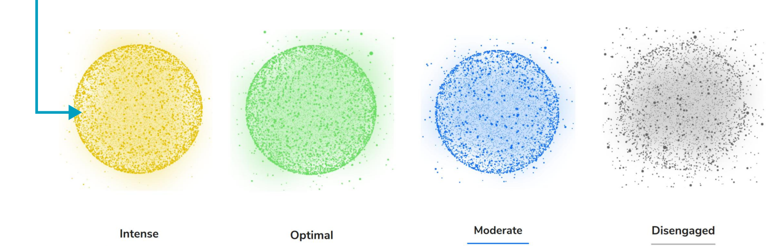


Fig 4.2.4. *Visualization of four cognitive efficiency metrics*

4.2.2 Generate design from research insights

Drawing from the interview insights presented in Chapter 2 and the literature review conducted in Chapter 3, several design solutions have been defined for transfer into a tangible design for validation purposes (see Table 4.2.1). For each issue, associated elements of EMOTIV are listed in Table 4.2.1 as well. To present the main concepts in a balanced manner, the first decision was made to build two informational interfaces: one for quick viewing during tasks and another for reflection after tasks. Additionally, to address the needs of "resonating with cognition data" and "more than data," two interactive interfaces are set up. (Fig 4.2.5)

Informational interfaces

Firstly, the informational interfaces would extend the concept of MWL by explaining it through the familiar term "stress" for users. This would involve introducing the EMOTIV indicators "Cognitive Load" and "Cognitive Stress" to explain MWL. Additionally, based on user interview insights, the information provided would be tailored for two different data usage scenarios (during work and after-work). The informational interfaces will be further categorized into two pages: "**Notification**" quick viewing and "**Current Status**" for providing detailed information. Furthermore, the elements in these two page should include metric, graph, and advice. (refer to Table 4.2.1)

Interactive interfaces

Oh the other hand, the interactive interfaces were categorized into "**Adjust**" and "**Saved**," aiming to facilitate interaction centered around adjusting states and establishing resonance with data. This approach addresses issues related to distrust of data and the necessity of strengthening the connection between the user and the data. To cope with these issues, calibration and emotional-adjustment strategies, metaphors and personalized historical data will be included in the ideation (refer to Table 4.2.1).

Detailed design descriptions can be found on the following pages.

Table 4.2.1. *Identified design solutions and elements*

User Issues from Chapter 2	Insights from literature review from Chapter 3	Design solutions	EMOTIV's elements
Stress, but not merely stress: value stress but interpret it well with MWL	• Stress is kind of **intense negative** response to MWL • Stress is kind of **warning sign** of poor cognitive resource allocation	• Strenghthen correlation between stress and MWL • Warning sign	• Cognitive efficiency metrics : Cognitive stress (CS), Cognitive Load (CL)
Enhance the connection: emphasize data's impact on people's lfe	• **No judgement** on MWL's performance • **Sustainment** is the main issues • **Entering another status** can be a difficulty	• Advice of changing status	
Resonating with the cognitive data: build users' trust on data	• If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users • Allowing the user to **calibrate data or set their own objective** • Support for Testability	• Provide graph instead of numbers • Calibrate data	• Line graph of CS andCL
More than data: help users develop understanding or interacting with data in a different way	• Allowing the user to **build up a personalized historical data** • Using **Metaphorical abstraction** to stimulate reflection in the user • To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive**	• Personalize historical data • Using metaphor • Emotional adjustment strategies	• Visualization of four Performance metrics
Providing right information at right times: reduce negative experience	• **Segmenting information** to reduce users' burden • Different levels of **data abstraction** stimulate different levels of reflection	• Data segmentation • Data abstraction	

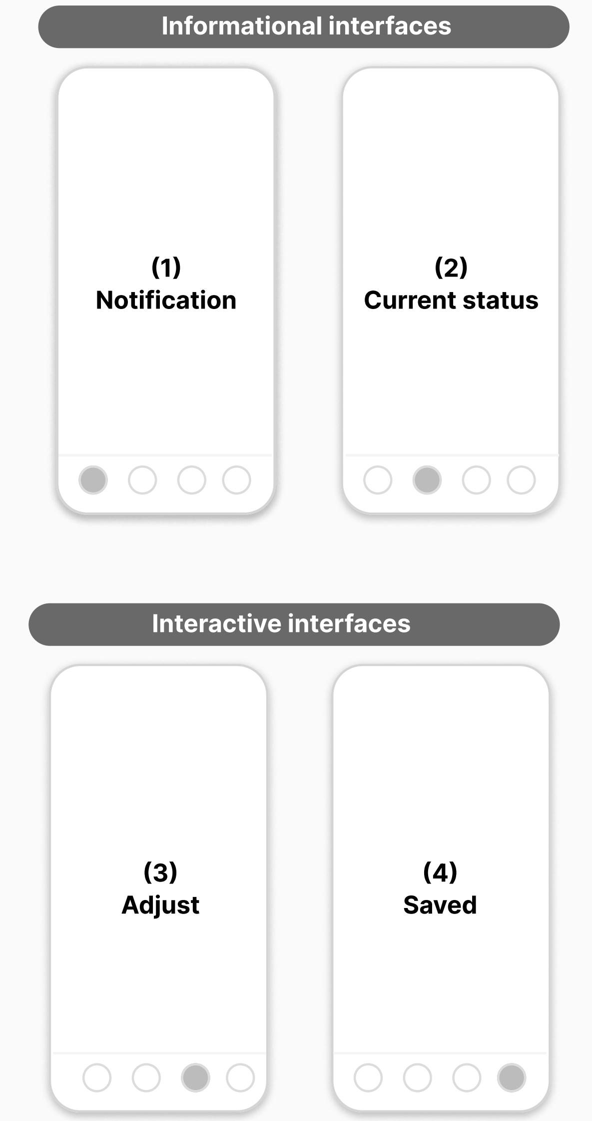


Fig 4.2.5. *Overview of four main pages*

4.2.3 Design details of prototype

Core elements

- Metric, shortcuts

Design goal of lock page

- Reduce the impact on tasks and seamlessly integrate data into everyday contexts in the most natural way
- Present the most succinct information with cognitive performance metrics
- Extend the duration of user interaction and provide proactive and continuous information
- Provide shortcuts to primary functions

Lock page

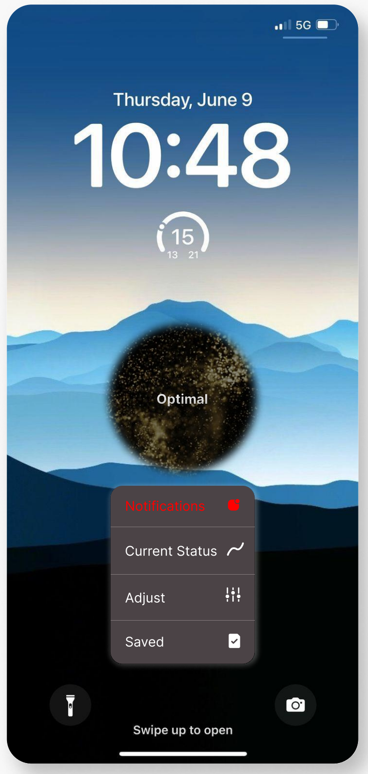


Fig 4.2.6. Demonstration of lock page

Core elements

- Metric, reminder, suggestion

Design goal of Notification page

- Designed for **quick viewing**
- With minimal information, only presenting metrics, reminders, and suggestion (actionable information)
- Alarm of sustainment issues (need to change current status)
- Try offering different types of messages, such as simple everyday conversations or encouraging feedback to maintain a connection with the user

Notification Page

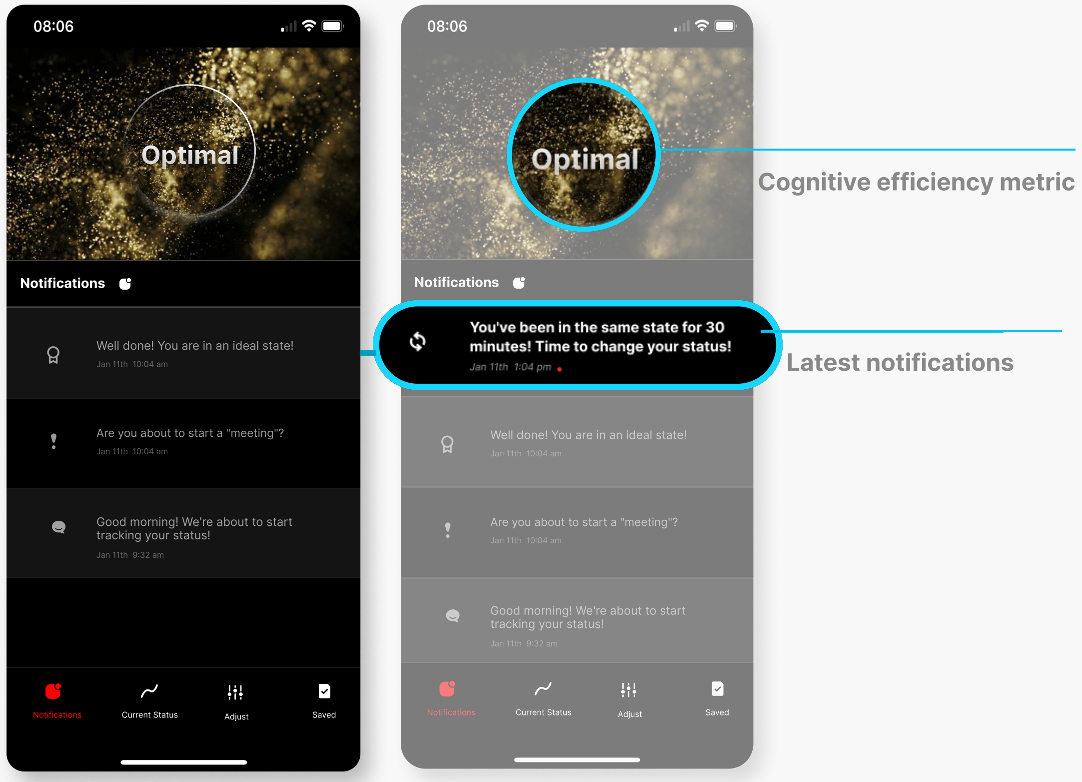


Fig 4.2.7. Demonstration of notification page

Core elements

- Metric, graph, calendar, suggestion, numbers, timeline

Design goal of Notification page

- Designed for **afterward reflection**
- With detailed information, including derived metric (i.g. Optimal) and metric contributing to derived metric (i.g. Cognitive Load) (medium level of abstraction)
- Present graph instead of solely number (for accuracy concerns)
- Connect to life events-google calendar
- Provide suggestions

Current status Page

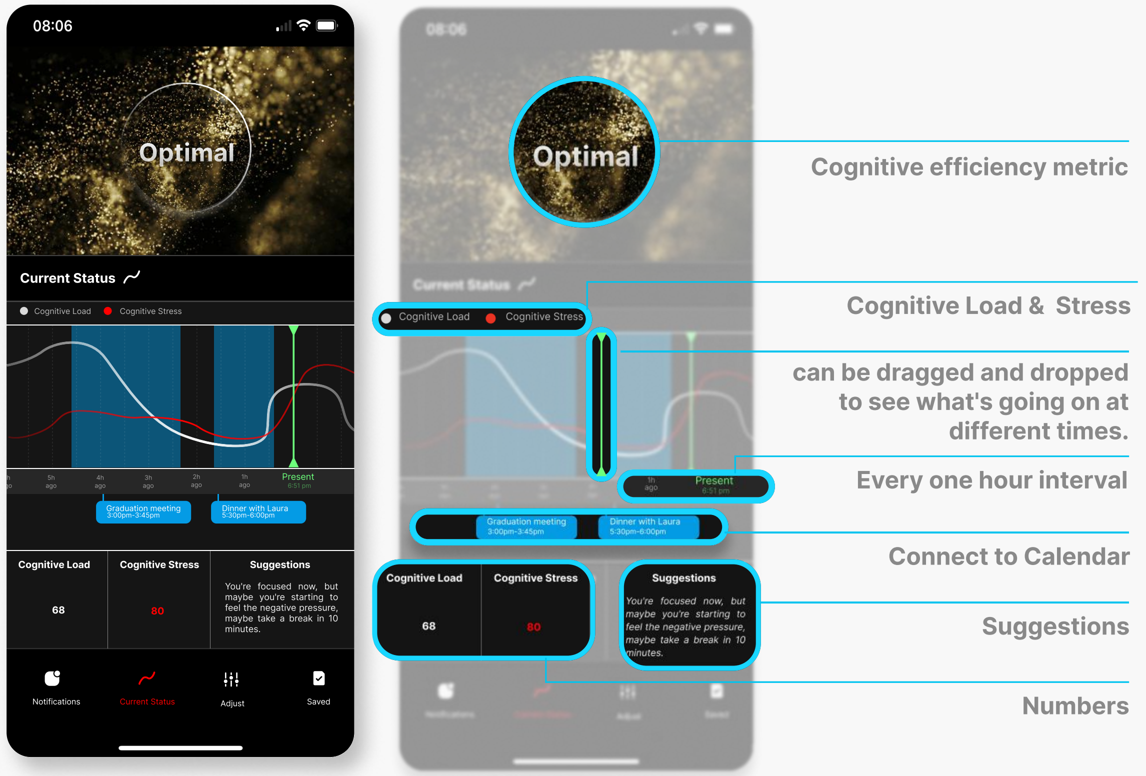


Fig 4.2.8. Demonstration of current status page

Core elements

- Metaphors, changing numbers, text instructions, tapping interaction

Design goal of Notification page

- Designed for **during task to adjust status**
- Maximize the visualization of cognitive performance metrics by using metaphors such as the speed, color, and flame of moving light dots to represent cognitive load and stress.
- Design prompts for adjusting states through screen tapping and breathing reminders.
- Provide animated changes in numbers to enhance the correlation between data changes and background states, in order to stimulate resonate with data changes

Adjust Page

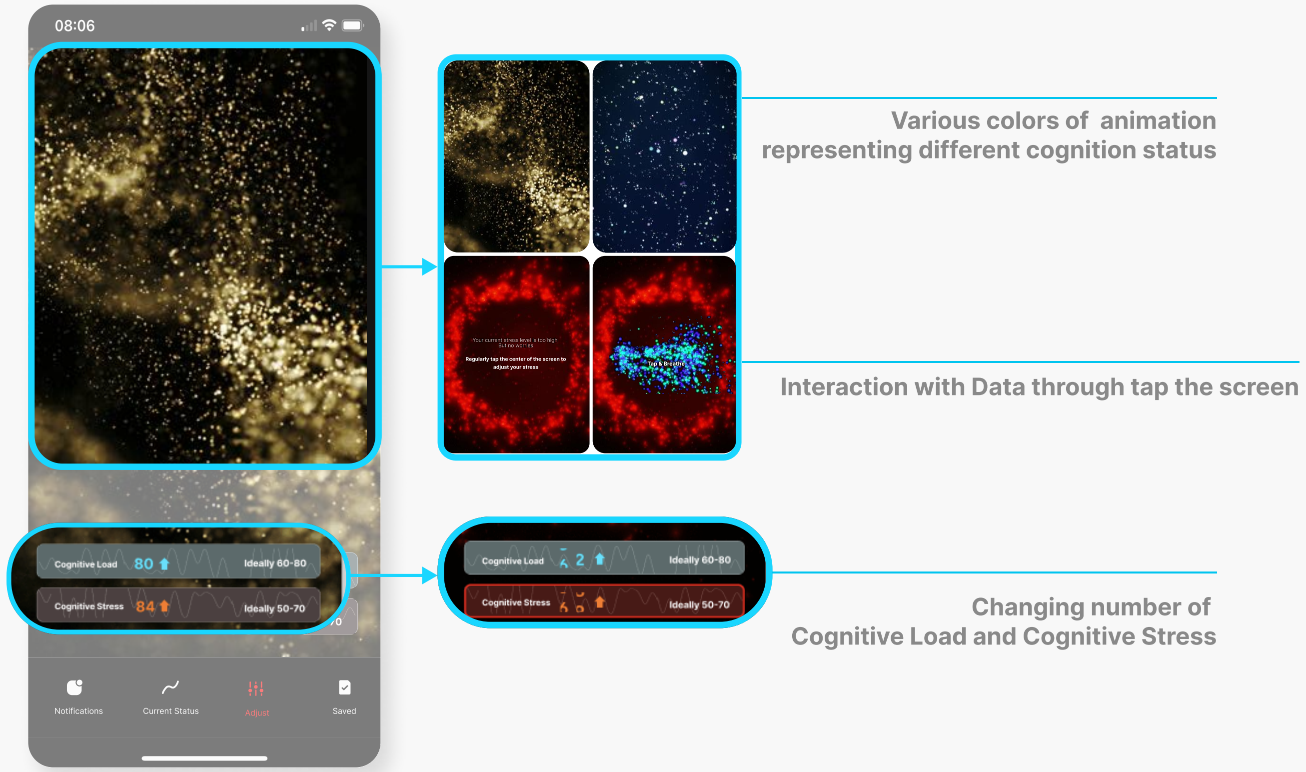


Fig 4.2.9. Demonstration of adjust page

Core elements

- Metrics, number, button"save current status"

Design goal of Notification page

- Designed for **afterward reflection**
- Show how derived metrics are defined through other indicators with specific numerical displays
- Place a button "save current status" for an open-ended discussion on whether they expect to calibrate metric or solely save meaningful data

Saved Page

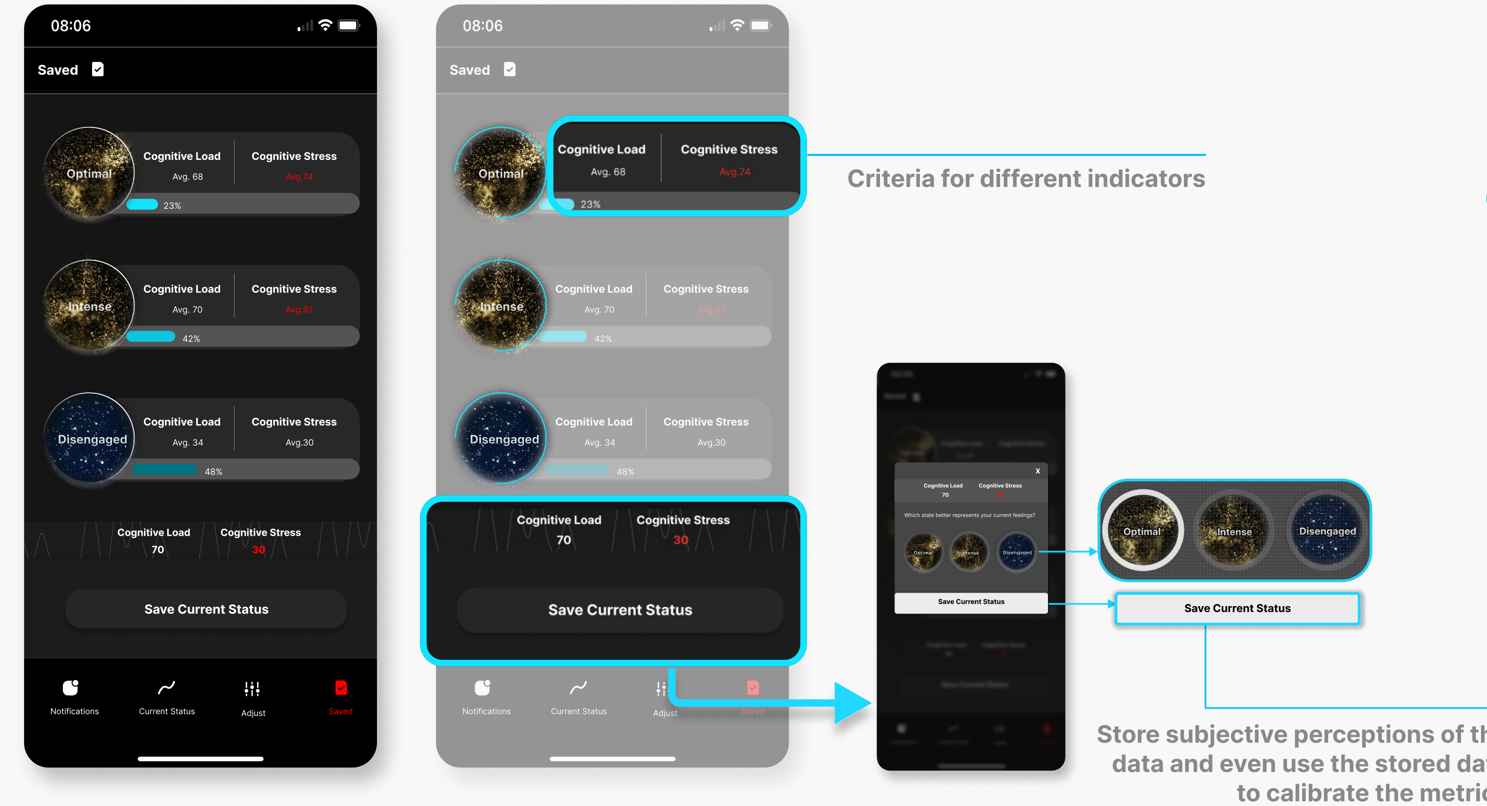


Fig 4.2.10. Demonstration of saved page

4.3 User test Results

The aim of this test is to explore user behavior during the data collection stage, defined by Li et al. (2010). As shown in Table 4.3.1., the main discussion centred around timing of using cognitive data, users' understanding and priorities of various function. Experience of wearing the self-tracking device were explore as a warm-up discussion to see whether physical experience would make any impacts.

Therefore, the results of the user test are mainly divided into three sections (See Fig. 4.3.1.)

Table 4.3.1. *Interview Questions after tasks*

Keypoints	Research Goal	
First experience of wearing the device (warm-up)	Explore the impact of wearing device Understanding timing of tracking MWL (wearing device)	1. How was your first experience of wearing it? pleasant? distracted? comfortable? 2. You've been wearing it for nearly 15 minutes, do you think you can wear it longer? 3. Will you want to wear it again in the future? If so, when do you want to wear it? why?
Timing of using the app	Discover the information needed at different times	1. Do you remember the moments you checked the app? When was that? and why do you want to check at that moment?
Functions in the app	Explore the user's understanding each functions	1. Have you tried all the functions? Which functions have you tried or have not tried yet? 2. Can you explain how you understand each function? What information are you interested in most?
Priorities of needs	Explore the importance of different functions and elements to the user	1. Here are some small cards, and I would like you to prioritize them in terms of Must have, Nice to have, unnecessary. Also, if you don't see the content you're looking for, you can add it yourself.

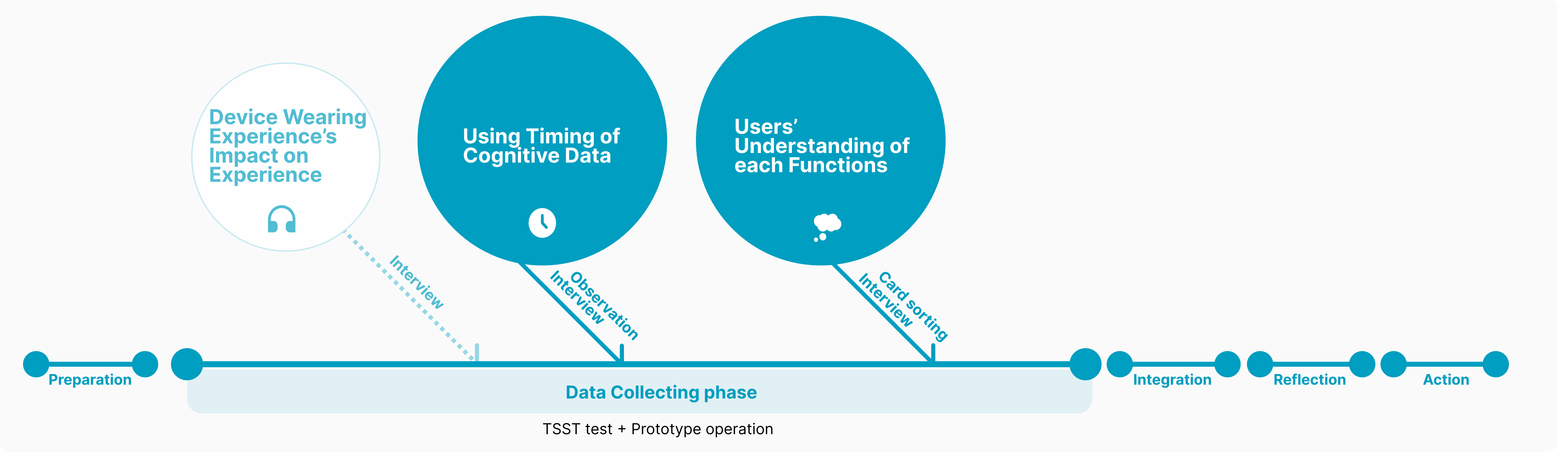


Fig 4.3.1. *Overview of user test results*

Timing of Using

To understand when users might want to utilize data (reflection), besides observing participants' actions during tasks , interviews were conducted to gain insights into the reasons behind their behaviors.

Results of observation

The usage of data by participants during tasks is recorded as shown in Fig 4.3.2. Out of ten participants, three did not use the prototype throughout the entire process. One participant used it before the task commenced, while participants two through five utilized it after the tasks. Additionally, one participant used it during the speech recording.

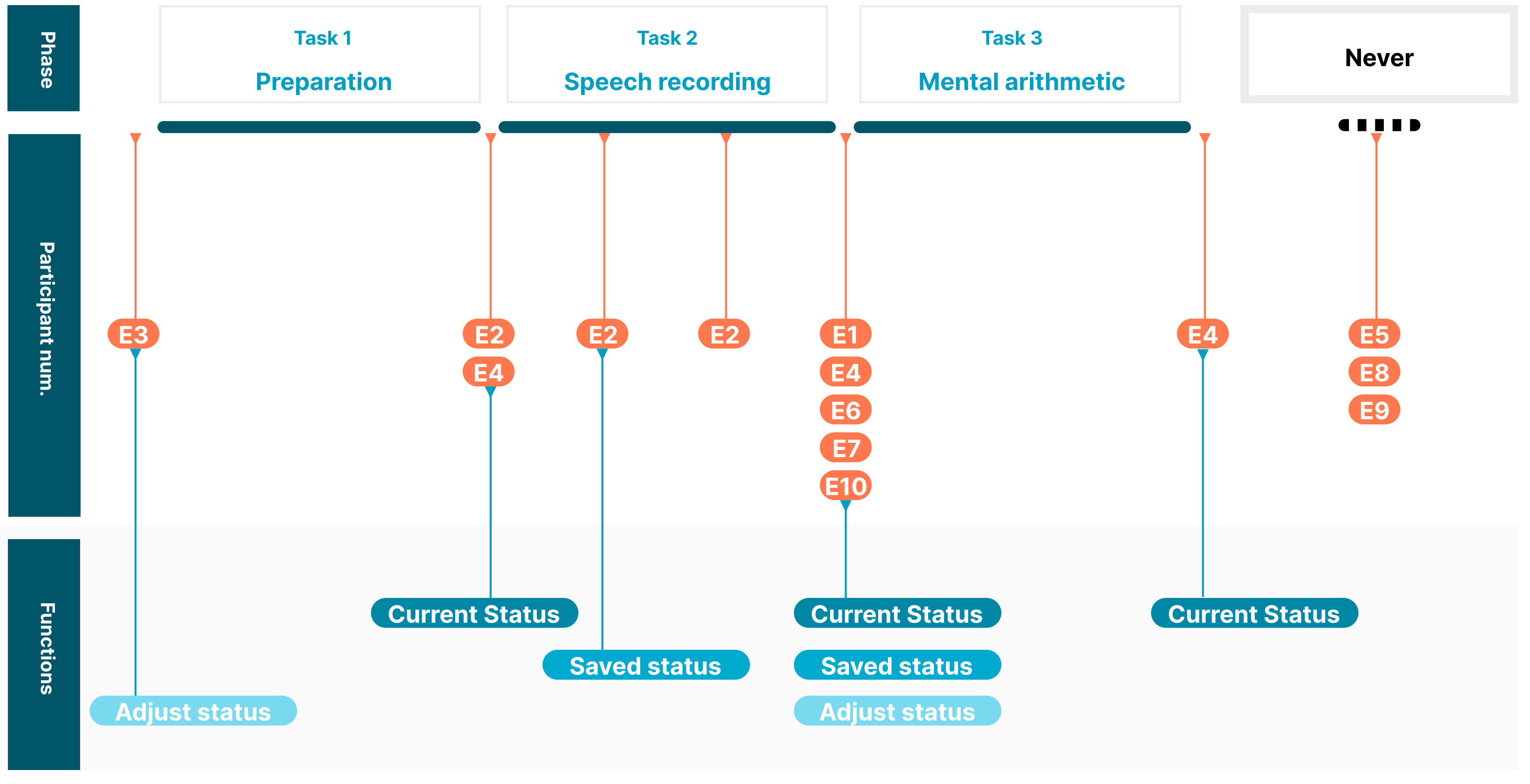


Fig 4.3.2. Results of observation during the user test

Use reasons

Participants were asked to describe the purpose of each use, with those who had not used the prototype explaining when they expected to use it. Eventually, the entire discussion generates four timings and five reasons, as shown in Table 4.3.2.

- **Staged reflection**

Reflection primarily occurs after tasks, with participants stating that their purpose is to see if there are any noticeable issues, but not necessarily to make improvements.

- **Observing changes**

After tasks, especially those of a special tasks such as video recording, users are particularly keen on observing their own changes and data validation.

- **Improving performance**

The pursuit of improvement may occur both during and after tasks. During tasks, the primary aim is to adjust the current situation. For example, some participants expressed a desire for a calm and relaxed state during their video interviews. Therefore, if they feel off during the task, they may want to confirm their state. Adjustments after tasks are to understanding oneself and then rescheduling accordingly.

- **When necessary**

For some users, they won't proactively check such data unless the system sends notifications to them. For these users, they only pay attention to significant changes in their state that attract their attention to make changes.

- **Flexible timings**

Many participants pointed out that they do not have a fixed time for reviewing data, depending on the nature of the task and when they feel performance is poor. It is worth mentioning that when users are using data at a random timing, they tend to have interactive features.

Table 4.3.2. Interview Questions

Timing	Reasons

After tasks (5/10)	• Staged Reflection
	  • Critical reflection
	• Observing changes
	• Improving performance
	  • reschedule
	  • adjusting current status

During the task (1/10)	• Improving performance • adjusting current status • Understanding current status
When Necessary (1/10)	• Receiving notifications
Flexible timings Feel bad (5/10) / Depends on tasks (1/10)	• Seeking for interactions

Understanding and Priority

In the interview, each interviewee discusses their understanding of four functions in turn. The discussion questions include: What message or purpose do you think this function is expressing? Where do you place your primary focus? What parts of this page do you find confusing? Have you noticed any particular information?

On each page, the research have included predefined checkpoints (Fig 4.3.3) to verify whether participants have noticed or understood the information and to confirm their comprehension of the overall functionality. Furthermore, the results of card sorting (Fig 4.3.4, Appendix C) will be discussed at the end of the discussion for each function.

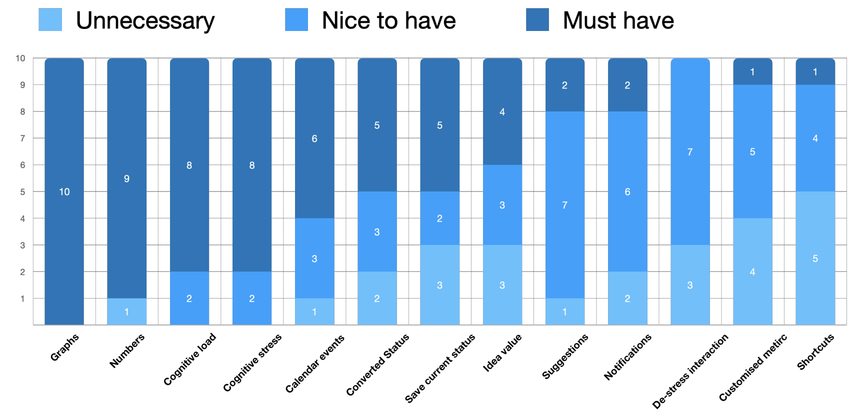
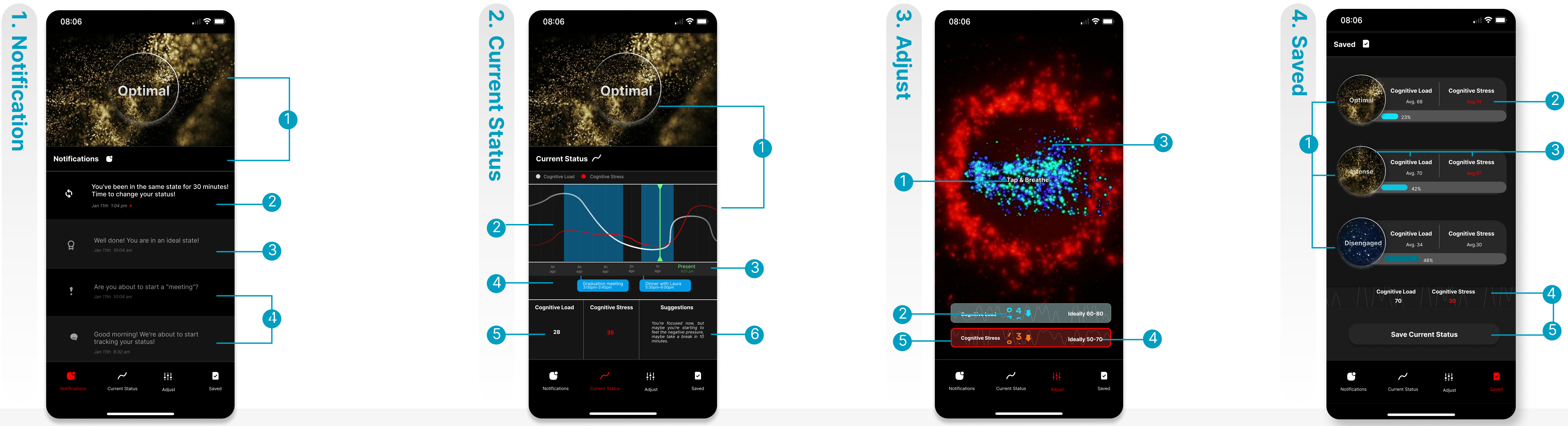


Fig 4.3.4. *Overview of results of card sorting*



1. Simplified information for quick reading
2. Suggestions for switching status
3. Notification of entry into the desired state
4. Lifestyle Dialogue

1. Discover relationship between metric and gragh
2. Explore relationship between Cognitive load and stress
3. Timeline
4. Connect to life events
5. Number
6. Concrete suggestions

1. Tapping interactions
2. Changing numbers of CL and CS
3. Engaging metaphor of metric
4. Ideal value
5. Highlight the undesirable value

1. Standard of four efficiency metrics
2. Personalized data
3. Discover relationship between metric and numbers
4. Simply save current status
5. Save for calibration

Fig 4.3.3. *Checkpoints of each page*

Understanding and Priority

Notification page

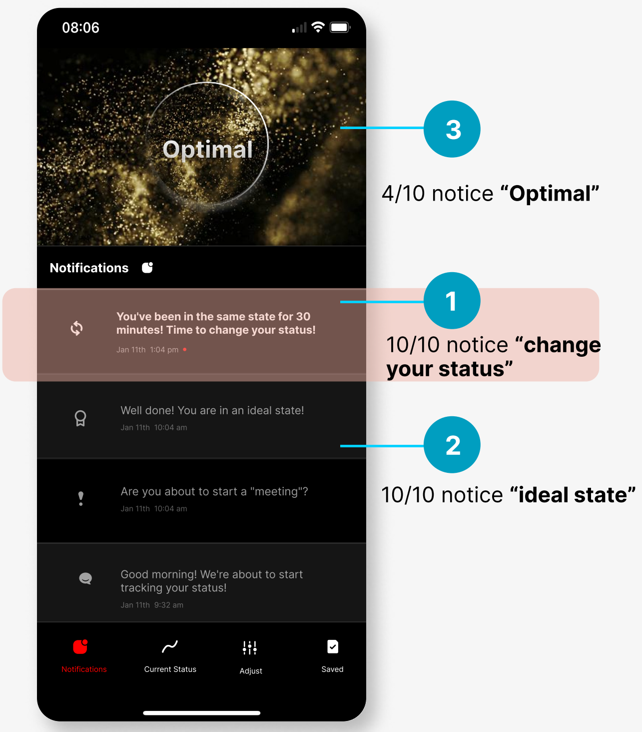


Fig 4.3.5. *User's focus of Notification page*

- X Simplified information for quick reading
- 2 Suggestions for switching status
- 3 Notification of entry into the desired state
- 4 Lifestyle Dialogue

Overall impression

Overall, this functionality appears to be user-friendly and easily comprehensible. Users seem to grasp the integration of "Critical Messages (10/10)," "Reminders (10/10)," and "Suggestions (7/10)."

In terms of attention, some people considered the indicators above as background and focused most of their attention on "change your state" and "ideal state". (Fig 4.3.5)

In the checkpoint section, the first part wasn't achieved. Reasons explained below.

Unwanted mixed messages from the past

Surprisingly, many participants (5/10) have specifically noted that this functionality may not be entirely suitable for "in-the-moment" use. They expressed concerns that the interface is cluttered with a lot of past information (e.g., "30 minutes ago"), and they feel that the relevance of this information to the current situation may be low.

"I didn't pay much attention because when I'm in work mode, what happened in the past doesn't matter to me. Like, if it's about, say, what your brainwave pattern was like in the past hour, I don't really need to know that right now. I'm more interested in knowing my current status. (E2)"

Undesired suggestion

"Change your status" is an insight derived from the literature review, aiming to encourage users to form a MWL cycle. However, some participants (3/10) have raised the concern that this suggestion isn't useful for them because their perception is, "You want me to rest, right? But how can I possibly rest?"

"If I'm deeply focused on something, I'll want to finish it quickly because I'm a goal-oriented person. Even if I'm intense, if there's a task in front of me, I'll push through to get it done.(E1)"

However, changing states doesn't necessarily mean going directly from intense to disengaged. It's just that users tend to think in extremes – either working intensely or resting completely. Perhaps future design iterations could provide more specific suggestions, such as "You can listen to music" or "You can switch to another task." The definition of transitioning between different levels of states isn't clearly defined, but it could be a topic for further research how to describe it can be more acceptable and actionable.

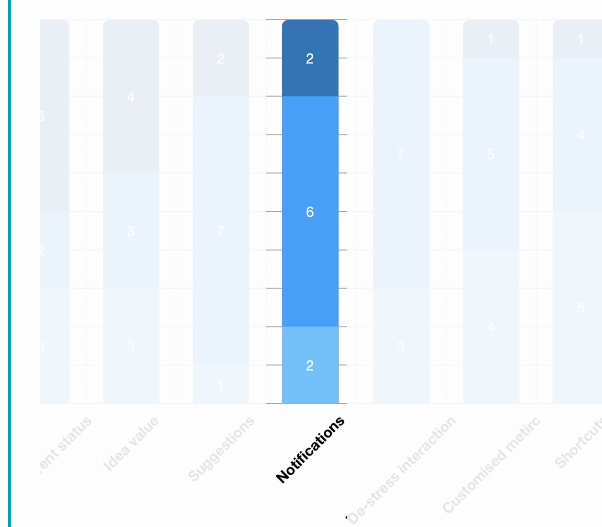
" it's not an actionable notification I will say (E7)"

What if ideal state do not fit users' goal

Although most participants did notice the system's push towards the ideal state, some participants (4/10) raised concerns about whether presenting such subjective information is appropriate, especially when they may not have time to review these messages. Participants pointed out that the system-defined "optimal" state may not align with their own definition of the best state. In such instances, this type of message may fail to impress users.

"It feels like this system sets its own "ideal" status and then tells you whether you've reached it. But I'm wondering if this "ideal" is something I've chosen or if it's just the system's own idea of perfection. I'm leaning towards the latter because it seems like the system has its own standards. But since these reminders don't reflect my personal goals, they might not feel as relevant or important to me.(E8)"

Not necessary function



Maybe it's because of these reasons that six participants categorized this feature as "Nice to have." Overall, everyone acknowledges the significance of this feature, such as providing crucial reminders during key moments, which is a reasonable function of this technology. However, there's still room for reconsideration regarding the content and manner of the reminders.

"For me, the main purpose of this app is to remind me of things. Whether it's reminding me to open it when I have something to do or giving me real-time reminders, I think that's its most important function.(E9)"

"I reckon it's pretty crucial to get some cheers when I'm feeling good and a bit of guidance when things aren't going so great. It shows me that the system isn't just watching over me but can roll with the punches. Still, it's not a must-have...(E5)"

Understanding and Priority

Current Status page

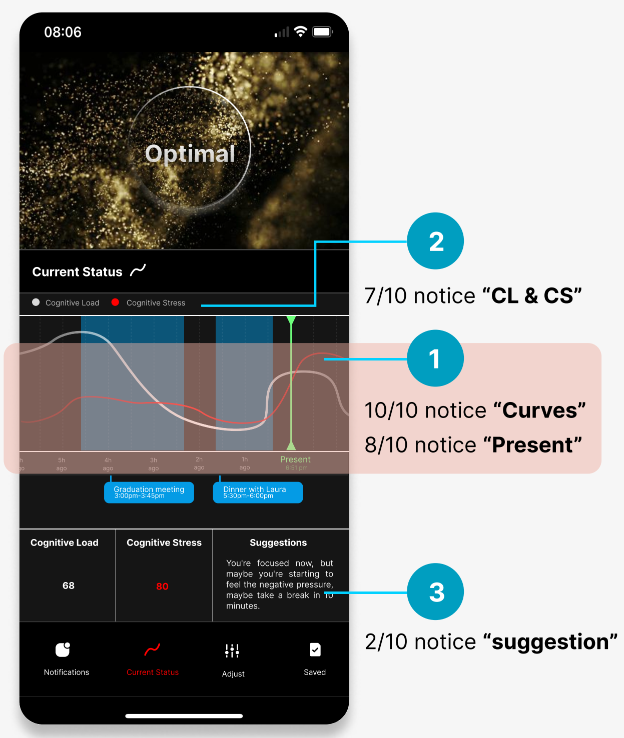


Fig 4.3.6. User's focus of Current Status page

Overall impression

In general, participants intuitively understand this functionality from the term "Current status." Most participants perceive it as a "review of the state within a few hours (7/10)" or simply as "the current state (3/10)."

It provides rich information, including metrics, charts, calendar events, and suggestions. Although most people focus only on the central chart area, including the curves and the timeline. (Fig 4.3.6)

- ✗ Discover relationship between metric and gragh
- ✗ Explore relationship between Cognitive load and stress
- 3 Timeline
- ✗ Connect to life events
- 5 Number
- 6 Concrete suggestions

In the checkpoint section, the first, second and forth points weren't achieved. Reasons explained below.

Need explanations on curves

Although everyone agrees that the curves are the most attention-grabbing and provide the richest information, only one out of ten participants correctly explained the meaning of Cognitive Load.

The remaining participants either noticed these two lines not until the discussion phase (6/10), didn't understand the meaning of these curves at all (8/10), or simply focused on Cognitive Stress while ignoring Cognitive Load (5/10). The common question among many participants was, "What does this mean? Isn't this just a chart related to stress?"

"I'm still not quite sure what "cognitive load" is. I have a rough idea of what stress is, but I'm not sure about "load." I'm also unsure why there are two lines. Aren't we just detecting my stress? (E8)"

In reality, when looked at separately, participants could provide a rough explanation. However, the biggest issue was that they couldn't understand why these two curvea were presented together. It's evident that merely presenting information together isn't enough to stimulate people's thinking. After explanation, all participants expressed a liking for the concept depicted by the chart, but they needed an explanation to fully understand it.

"To be honest, I didn't really get what "Stress" meant at first, but I found it super interesting when you explained it just now. I actually liked it a lot. It just need more explanations(E1)"

"I think I need this chart, but mainly because I want to see its explanation. If you just only show me the chart, it feels like I'm writing a paper and have to figure out the insights by myself.(E10)"

Surprisingly focus on timeline

Unexpectedly, many participants (3 out of 10) mentioned issues regarding the timeline. They felt that the current timeline was too long, and they only needed data for one or two hours because they mentioned their focus typically lasts for only one or two hours, or they break down their work into one-hour units.

"I assume I'll be using it most often for work. Personally, I tend to break down my work time into hours because my focus lasts for about an hour at most. So, I'd prefer it to maybe use hours as the unit to help me understand better.(E2)"

What's interesting is that presenting only an hour data gives them a sense of focus on the "now" and sparks a desire to improve their performance within that hour. However, when presenting data for multiple hours or even a day, users don't feel compelled to reflect on their current situation.

"I feel like this page... has too much information as well. I understand that the green line represents my current status, and it shows the pattern from many hour ago. But why...? I feel like I'd distinguish between two time points: one for immediate viewing and another for reviewing later. For immediate viewing, I'd prefer the most straightforward results, not a combination of many data(E3)"

Sensible data? Sensible calendar?

Possibly due to design issues, few participants noticed the calendar. The decision to link to Google Calendar was partly because EMOTIV itself has the functionality to connect to third-party calendar platforms, and partly because it was thought to be the most time-saving way for users to import events.

However, three participants discussed how there were many "events" on Google Calendar that weren't suitable for inclusion in this app, such as leisurely dining events or personal appointments. Interestingly, one participant mentioned that, compared to their brain data, their Google Calendar was more private. They wouldn't want an app to know about their private schedule.

"But I feel like...this app doesn't need to know the specifics of my schedule. You just don't want it knowing too many detailed things. You only need it to know when you're doing the same thing. It could have a feature like marking...In terms of privacy, I feel like my calendar is more sensitive than my brainwaves.(E2)"

Personalize labels

However, it's undeniable that many participants appreciated the benefit of linking with life events, as it allows them to see more useful information, like making comparisons on the same tasks. Therefore, they suggested the possibility of customizing simple labels, such as categorizing tasks as analytical or creative work, which would be more helpful for them to make comparisons.

"So now it's become crucial to know what I'm currently doing. Can my calendar help me categorize what I'm currently doing, rather than just listing what I've done? Or it's not hard to make comparisons.(E5)"

Users are willing to provide more information

Only two participants paid attention to the suggestions, and their reasons were similar to those explained on the notification page. They felt that suggestions were optional references. Additionally, they believed suggestions couldn't be objective because various personal factors, including sensitivity to stress or their own constitution.

"From a scientific perspective, I think because there's a lot of information about a person's life that are noy collected here, it's hard to make judgments about my life and give suggestions based on just this tiny bit of data... If someone were to give suggestions like that, I wouldn't trust them much.(E9)"

However, one participant suggested that to make the suggestions or analysis more objective, the app could ask users to provide some simple physiological or psychological records, similar to period-tracking apps (refer to Fig 4.3.7), and then offer more comprehensive explanations. It's worth mentioning that users may not necessarily require accuracy because suggestions are inherently personalized. But if it can help users identify some influencing factors, it would add a lot of value to this technology.

"I feel like if this app were to give me suggestions, it could be like those period-tracking apps. They don't only track your menstrual cycle but also your mood and physical reactions every day...So, this app might not just help me judge if I'm stressed or not, but through some simple input of my own information, I could give the team behind it some data to analyze what my state might be. Having a conversational interface could work too... The simplest way could be to have a Q&A page where users can find their own answers. Maybe as you browse it, you might think, "Oh yeah, this could be a concern too." It doesn't have to be super accurate, but it could help you catch some potential issues.(E5)"

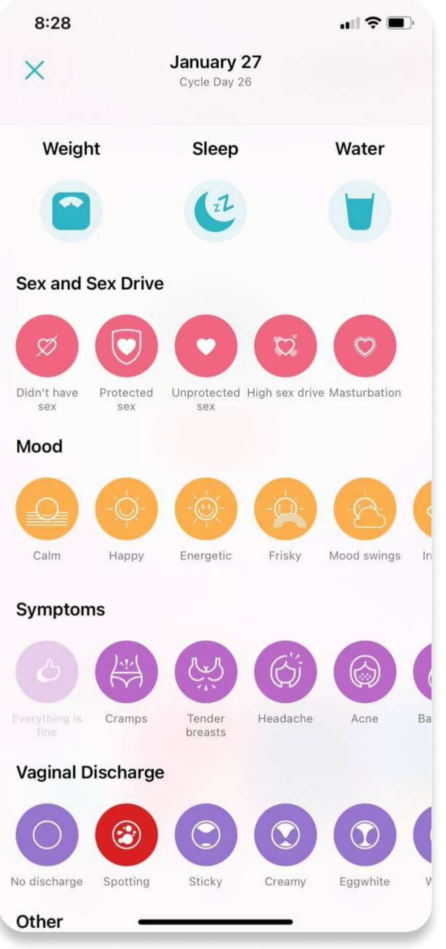
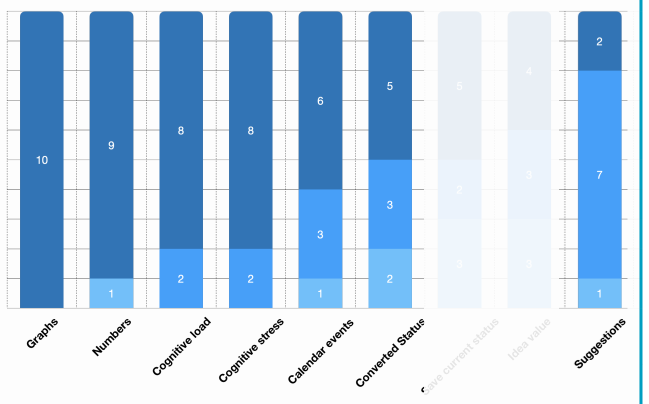


Fig 4.3.7. Reference of life record in a period tracker

Must-have function in general



Overall, almost all the information and functionalities on this interface have been rated as necessary, except for suggestions, which are categorized as "Nice to have."

It's worth noting that when discussing the importance of numbers, graphs, and metrics separately, some participants indicated that graphs were the most crucial, while others believed that all of these pieces of information should coexist, as it would otherwise be challenging to comprehend separately. This echoes the literature discussing how a moderate level of abstraction can trigger the best reflective thinking.

"If I were to compare numbers and graphs, I'd say I want to see how they change over time, but I wouldn't just want to know the actual numbers. It's the same with cognitive load and stress. If they exist separately, they wouldn't make sense to me. They have to appear together for me to understand.(E5)"

As for Suggestions, most users currently classify it as "Nice to have," indicating that while it's just a reference, it has the potential to develop into important information. It depends on how the product company designs this aspect of the information in the future.

Understanding and Priority

Adjust page

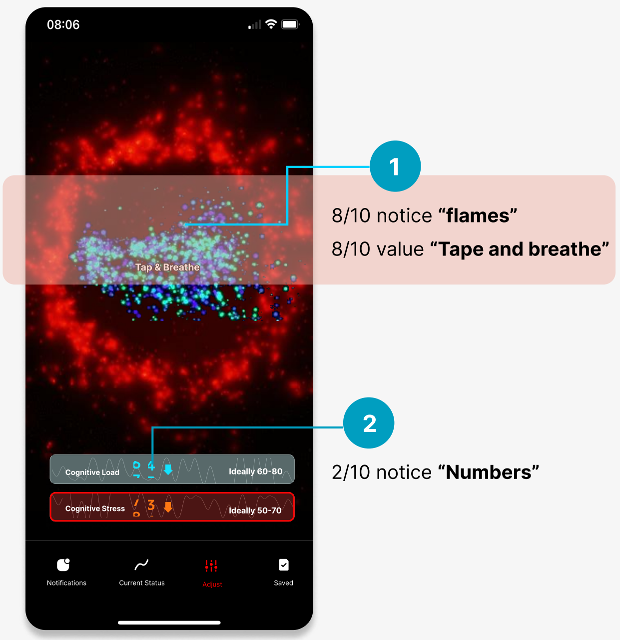


Fig 4.3.8. User's focus of Adjust page

Overall impression

Participants' understanding of this feature varies: "stress-relief mini-games" (5/10), "distraction" (3/10), "brainwave control" (1/10), and "visualization of cognitive load and stress" (1/10). Compared to other interfaces, participants' understanding of this interface is relatively inconsistent.

The "Adjust" interface facilitates state adjustment by providing visualizations of metrics, real-time numerical data, target values, and interactive touch points. It aims to help users perceive the correlation between numbers and their states.

However, similarly, perhaps due to the design being too complex or not intuitive enough, users' attention is focused on the visualizations (8/10), including the flames and tapping instructions, while ignoring the changes in the data (2/10). (Fig. 4.3.8)

1. Tapping interactions
- X Changing numbers of CL and CS
3. Engaging metaphor of metric
- X Ideal value
- X Highlight the undesirable value

In the checkpoint section, the second, forth and fifth points weren't achieved. Reasons explained below.

Adjustments needed for users only when under high stress

The original design concept was not only for extreme stress, but also for any time of the day to adjust the state through this interaction. However, possibly due to the overall visual design, this feature feels like a game or meditation for many participants. Moreover, users consider this feature useful during times of high stress, only when they feel stressful.

"I feel like it's something that helps me relax overall. It's kind of like a little break from my usual work, you know? Like, when I'm feeling tense, these visual can distract me.(E3)"

Eye-catching visualization do not arouse deeper reflection oncognitive performance

But actually, not many people realize that the concept of visualization was derived from the design of the Cognitive Efficiency Metric. Many simply focus on the changes in the movement of light dots, color, tapping, and texts. As a result, not every people notice the changes in numbers (2/10).

"I kinda prefer how images make me feel, like when you're meditating and focusing on your breath... You know, that little speck of light... It feels like there's some meaning to its movement. I picture myself breathing, and that light sorta expands with each breath... (E5)"

Number changes already mean a lot

While most participants focus on visualizations section, there are still two participants who are drawn to numbers. They believe that the changes in numbers are sufficient to provide them with a sense of resonance. One of them particularly pointed out that visuals don't always change, but the changes in numbers are more frequent and immediate. Thus, in comparison to visual metrics, they prefer to see visualizations of cognitive stress and load.

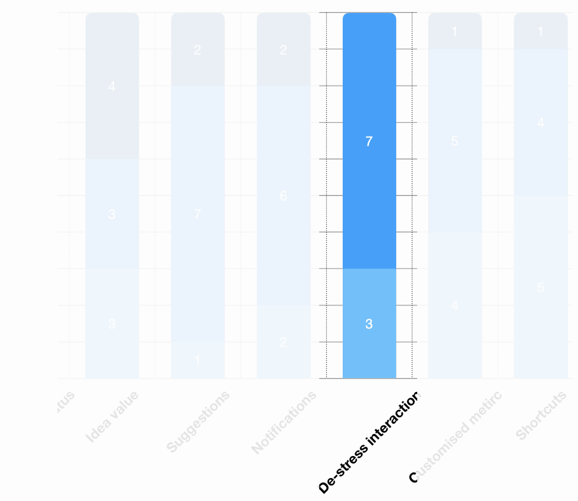
"If the background image stays the same without much change, you still need to check the number to know whether you're adjusting your state or not right? (E5)"

Disconnect between brainwaves and the changes in the graphic

What's particularly interesting is that one participant had experienced a human-machine interaction where they could change graphics with their brainwaves. Because of that experience, this interface led him to think that the graphic might be influenced by his own brain data. So, they ended up focusing on the numbers. He also pointed out that changes in data provide a more continuous sense of variation compared to changes in graphics.

"I once tried out this brainwave detector thingy at an exhibition. It was supposed to let me control this graphic in front of me with my mind waves. So, there I am, thinking I'm all in control of this graphic, but later on, I started doubting it. I mean, sure, they said my brainwaves could control it, but I wasn't really sure if the changes in that graphic were actually because of me. 'Cause, you know, it didn't seem to follow any particular pattern or anything. (E5)"

Nice to have function in general



Regardless of participants' understanding of this feature, overall, it was categorized as "Nice to have". Because every participant mentioned that they already had their own habits for destressing or adjusting their state, like playing sports or chatting with others. They pointed out that while they could see the relevance of this feature to the app, having a standalone feature for user state adjustment wasn't necessary. They suggested integrating it into the Current Status feature and focusing on combining graphics with numerical changes.

"If I wanna chill, it'd be cool if it could just suggest stuff right here in the "current status" section. Like, maybe remind me to grab a drink or something. Just tossing ideas around... It's like, 'Hey, here's just one way to unwind.' It doesn't always have to be about gaming. And if this feature were to go rogue and become its own app, that'd make sense too. It just doesn't have to be stuck inside this app. I mean, it's pretty noticeable here, but it's not really a must-have.(E2)"

Understanding and Priority

Saved page

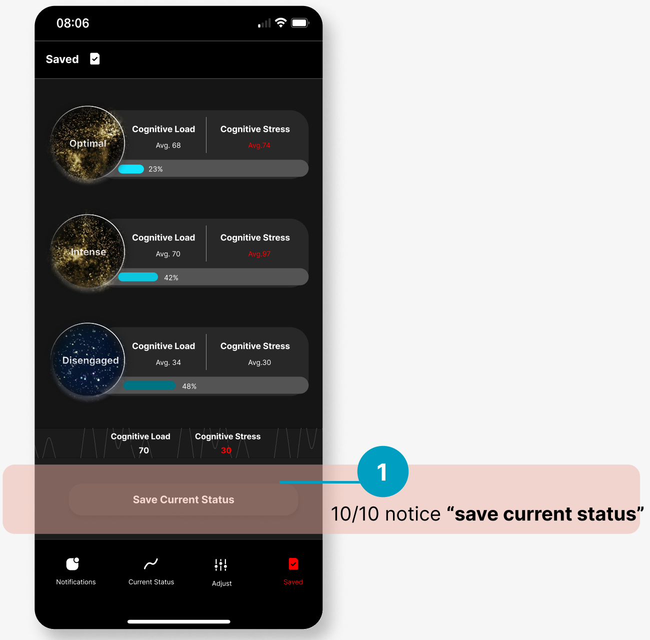


Fig 4.3.9. User's focus of Saved page

Overall impression

The term "saved" in this feature immediately confused participants. None of the ten participants could grasp the function of this interface at first glance.

However, the main purpose of this interface is to engage users in discussions about data transparency, data calibration, and personalized data concepts. In this interface, besides listing the cognitive efficiency metrics , it also provides standards of these metrics, such as "Intense" representing the state when Cognitive Load is 70 and Cognitive Stress is 97. In the area below the interface, there's a button labeled "Save Current Status." The design didn't elaborate on what changes would occur after saving, intending to encourage open-ended discussion about participants' thoughts.

Observation results indicate that due to the difficulty in understanding this feature, many participants attempted to comprehend it by clicking the sole button, without paying attention to the information above. (Fig. 4.3.9)

- X Standard of four efficiency metrics
- X Personalized data
- 3 Discover relationship between metric and numbers
- 4 Simply save current status
- X Save for calibration

Not sure about the significance of saving

It's actually quite surprising that no one could understand the meaning of saving cognitive data just from the term "saved". It might be because most users' attention was focused on the information in the "current status" page, making it difficult for them to grasp why or how to save such information. It could be a matter of wording or perhaps users didn't inherently expect to take any action regarding the accuracy of the data.

"I'm not sure what the point of saving is, and I'm curious about what happens after I save it?(E3)"

do not expect much control over the data

Although from early interviews and literature reviews, we observed users' concerns about data discrepancies, when we proposed the idea of enabling users to provide feedback to the system to correct data, users became confused instead. Many participants (7 out of 10) expressed that they weren't cognitive data experts and didn't want the responsibility of potentially disrupting the accuracy of the data calculations. They felt that providing feedback to the system, suggesting its judgments were incorrect, would essentially be self-deception and would defeat the purpose of using the product.

"I think it could include my own feelings a bit, but I wouldn't want too much control 'cause I'm not exactly an expert in this stuff. But if I do disagree with the data, I'd like it to give me more info(E5)"

Users found little significance in correcting derived metrics

Some participants (3 out of 10) noted that they didn't resonate particularly strongly with the four cognitive efficiency metrics compared to the two metrics (CL and CS) in the chart. Since the curve represents data using "relative values" rather than "absolute values," as long as there's continuous variation in the curve, users' skepticism about the data accuracy wouldn't be as high. This also aligns with the findings from earlier literature reviews. Participants pointed out that even if they corrected these four derived indicators, it wouldn't affect the chart results at all. In this case, they lacked the motivation to correct the derived metrics because, in the end, these adjectives and numbers were merely for reference. One participant even stated that they didn't expect the calibration feature because they believed the accuracy wouldn't vary significantly. Even if there were inaccuracies, they wouldn't be able to discern them.

"Honestly, since I'm not really familiar with these four indicators, they're just too vague for me. I'm not sure if I'll even notice any difference after I correct them.(E9)"

Comparing Indicator Standards: Self vs. General Population

Another interesting point of discussion arose when participants questioned whether the standards for these so-called system indicators were based on comparison with oneself or with others. Several participants cited the Body Mass Index (BMI) as an example, highlighting that the calculation standards for these standardized indicators are typically derived from data from a large sample size. However, when it comes to psychological data, they don't believe that comparison with others is meaningful because psychological data isn't as objective as physiological data. As regarding "suggestions", there may be too many immeasurable influencing factors. From a data science perspective, participants expressed that considering who they are comparing to, their interest in these derived metrics isn't as high.

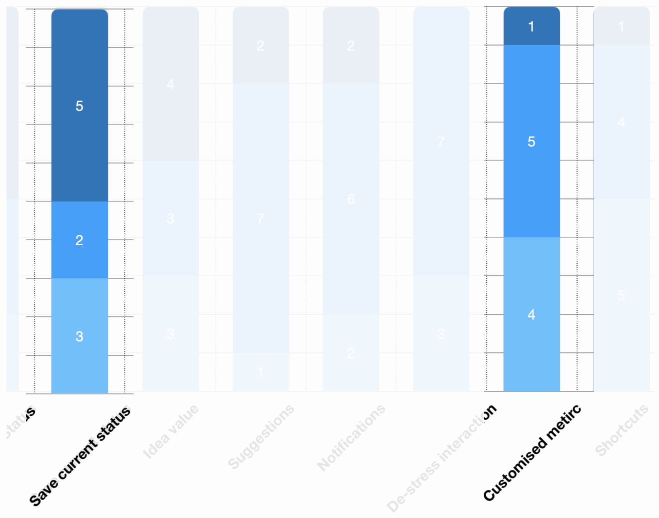
"I feel like this thing should compare me to myself... like, it should compare me feeling stressed today to me feeling less stressed yesterday, rather than comparing my stress level to someone else's.(E10)"

Storing data centered around "events"

Compared to directly calibrate metrics, many participants (8/10) expressed greater interest in building their personalized data repository. Their personal data repository isn't just a simple historical record but is centered around "events," such as whether there's a difference in math performance between today and yesterday. For these participants, the purpose of saving is for later comparison and reflection. It would be more meaningful to them if the records were centered around their most valued work performance rather than just based on time.

"What I'm thinking is kind of like....I want to compare the same thing, so I'd only store data related to that particular thing.(E9)"

Must have "saving" but nice to have "customise"



In terms of importance card-sorting, participants highly rated "save current status," while for customized metrics (meaning calibrating data to personalize metrics), nearly half of the participants deemed it unnecessary or suggested it could coexist without affecting the original data.

"I reckon it'd be handy to set up my own range, but I'd like to keep both my version and the system's default. That way, you still get an average from the system to give you an idea of what state might be better.(E8)"

Device Wearing experience's impact on design

As an icebreaker for the interview, participants were asked about their overall experience wearing the device, their willingness to wear it, and the duration and timing of wearing. This topic generates five key points, and two main insights.

Five key points

Uncomfortable product wearing experience

Nearly half of the participants discussed negative experiences with wearing the product, citing feelings of discomfort (2/10), insecurity (2/10), and bulkiness (2/10). Consequently, they believed the product was unsuitable for outdoor use.

Invisible Data Tracker

However, over half of the participants (6/10) indicated that wearing the device did not affect their work tasks, as they did not perceive their brainwaves being tracked (6/10), and the overall experience was similar to wearing headphones (4/10). Some participants even expressed that the process of wearing the device intuitively helped them focus on tasks, as wearing headphones during work was already a common habit for many people.

Limited wearing time

Due to the association with wearing headphones, over half of the participants (7/10) expressed reluctance to wear headphones for more than an average of 2.5 hours. This duration represents either the participants' maximum limit of attention or their maximum tolerance for discomfort product wearing experience. Additionally, three participants raised safety concerns, expressing worries that prolonged wearing might affect the health of their brainwaves, despite not feeling their brainwaves being monitored. They noted that their sensitivity to their head was higher than to their limbs.

Overthinking and unnatural performance

While the overall user experience isn't entirely negative, it's also not considered a necessary experience by users. Three participants mentioned that although it didn't affect their work, wearing the device did lead them to overthink their cognitive performance (3/10). This might not necessarily be disruptive, but it could make one feel unnatural, similar to someone instructing you on how to breathe, causing you to struggle with natural breathing.

Unnecessary tracking

Among the 10 participants, 3 indicated that they didn't feel the need to use such a product, citing reasons different from those discussed in Chapter 2 of the interview. Apart from concerns already explored such as privacy infringement (1/10) and excessive confidence in health (1/10), 5 out of the 10 participants mentioned that their lifestyle changes were minimal, and they didn't expect to see significant reflections from short-term data. Furthermore, one participant pointed out that wearing a tracker made them feel constantly pressured to improve themselves, leading to stress. They believed that life didn't need to be taken so seriously.

Two main insights

Creating seamless experience

Considering factors such as the experience of wearing the product, the limits of human attention, and safety concerns, it's evident that users don't actually use the tracker for long periods. Additionally, the accumulation of short-term data lacks reflectiveness for some users. Therefore, if users' product usage time is inevitably segmented, finding ways to connect these dispersed experiences to encourage reflection could be a key consideration in design.

The advantages and disadvantages of invisible experiences

If we consider that the duration of each product usage by the user is actually short, and if, as some participants have mentioned, an individual's short-term lifestyle changes are not significant, could the invisible experience ultimately make the tracker seem dispensable and easily abandoned? Is the invisible user experience what product purchasers expect? Or does the invisible experience actually make people more concerned about the product? This could be a key consideration for subsequent design improvements.

4.4 Conclusion of User Test

Takeaways of use timing

- Many people typically utilize cognitive data after tasks. Most people tend to use cognitive data after tasks. The purposes of tracking after tasks includes critical reflection, confirming changes, rescheduling and making adjustments.
- There are some people who do not regularly check their data. For these users, interactions may be their primary motivation.
- Few people check cognitive data during tasks. A lot of people view it as a potential distraction during tasks.
- For passive users, notifications serve as their sole means of access to the data.

Takeaways of device wearing experience

- Tracking data is essentially an inconspicuous experience, as its wearing sensation closely resembles that of wearing headphones.
- Many individuals do not expect to wear tracking devices for long periods, often limited by their ability to maintain focus.

Takeaways of function understanding

- Ideal state and suggestions are not necessary for users as these information are considered to be personal.
- When it comes to cognitive performance, people do not want to be told what to change, which may make them feel offensive and meaningless.
- Instead of suggestions or adjustment guide, people prefer to explore the reasons of poor cognitive performances. Exploring something they do not know values more than data accuracy. To achieve so, users are even willing to provide with more data.
- Timeline serves as critical elements for users. Different time points and time intervals can provides different levels of information.
- Users desire more functions enabling them to personalize their own data library.
- Users expect this app to specialize in displaying cognitive data. While users don't anticipate perfect data accuracy, mere numerical changes can already convince them. However, users require more guidance on how to interpret graphs or metrics.

Chapter 05

Co design: Survey

5.0

In contrast to Chapter Four, this chapter centers on investigating the ways users record their cognitive data. An offline survey, which evolved into a booklet, was conducted for this purpose.

5.1 Research Methodology: Survey

5.2 Booklet Design

5.3 Results of Survey

5.4 Conclusion of Survey

5.1
Research Methodology: Survey

Purpose of Survey

Reviewing the planning outlined in Chapter 3.3, in addition to conducting user tests, this research also aims to understand, from the users' perspective, how they record their own workload. To accomplish this, an offline survey has been designed **to collect information on how users record their cognitive data.**

Moreover, building upon the insights from the interviews conducted in the chapter two, it was observed that users often use the terms “cognition”, “stress”, and “emotion” to express their understanding of MWL. However, their explanations for each term were not always clear.

Therefore, the aim of this survey is aslo to understand, from the users' perspective, **how workload, emotion, and stress are experienced and recorded throughout a day.**

Methodology & Recruitment

An offline survey was conducted, and **Ten participants** were recruited in total and through snowball sampling in TUDelft campus. As a result, all participants are students background. Similar to interview recruitment, the research didn’t require any specific background as everyone could be the users of Neurotechnology device.

Apart from their student status, this study does not collect any additional personal information from participants. All responses are handled anonymously, and the ten participants are randomly assigned identification numbers: **B1 to B10.**

Research Procedure

After receiving the booklet, the 10 participants have the liberty to choose any day to complete the recording. This study imposes no requirements regarding the timing or duration of completion. Participants are expected to return the booklet upon completion.

During the recording process, participants are required to complete three records: daily record of workload and emotion, daily record of stress, and reflection.

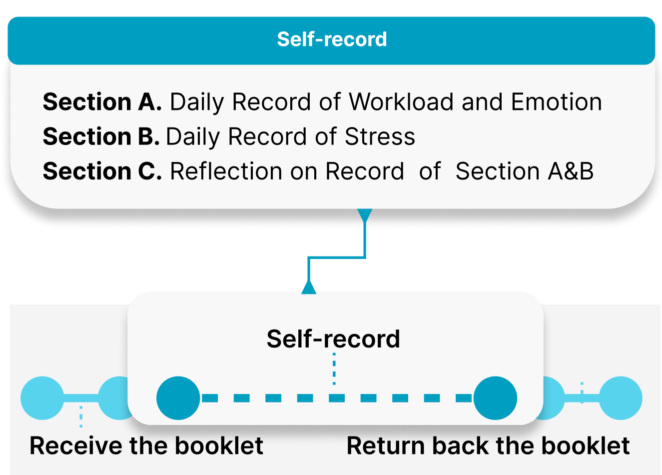


Fig 5.1.1. Survey Process

5.2
Booklet Design

The booklet consists of three sections in total, as already described in Fig 5.1.1. The cover of the booklet includes instructions regarding the activity.

Sections A and B encourage participants to express their thoughts and imaginations about workload, emotion and stress through visualization, while section C asks participants to reflect and provide suggestions through written descriptions.

Participants are invited to select a day of the week that they feel represents their typical workload and emotion, and record on an hourly basis from 8 am to 12 pm.

Regarding the specifics of each section, after reviewing the research insights from Chapters Two and Three, various questions that can be addressed through the booklet are listed, as illustrated in Table 5.2.1.

The specifics of each section are outlined in the subsequent pages.

Table 5.2.1. Identified questions of booklet design

User Issues from Chapter 2	Insights from literature review from Chapter 3	Question of Booklet design
Stress, but not merely stress: value stress but interpret it well with MWL	• Stress is kind of **intense negative** response to MWL • Stress is kind of **warning sign** of poor cognitive resource allocation	• What are people's perceptions of workload and stress, respectively?
Enhance the connection: emphasize data’s impact on people’s lfe	• **No judgement** on MWL’s performance • **Sustainment** is the main issues • **Entering another status** can be a difficulty	• What do people value in their record?
Resonating with the cognitive data: build users’ trust on data	• If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users • Allowing the user to **calibrate data or set their own objective** • Support for Testability	• How do people define their stress?
More than data: help users develop understanding or interacting with data in a different way	• Allowing the user to **build up a personalized historical data** • Using **Metaphorical abstraction** to stimulate reflection in the user • To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive**	• How do people summarize their workload and stress?
Providing right information at right times: reduce negative experience	• **Segmenting information** to reduce users’ burden • Different levels of **data abstraction** stimulate different levels of reflection	• What kind of notes people will make during recording?

Section A-Workload & Emotion

Regarding workload record, participants are free to use any kinds of ways illustrating their workload, such as pie chart, line graph, or any other preferred formats. As for emotion record, it refers to "The Circumplex model of emotion," proposed by James Russell in 1980.

The primary aim of this model is to elucidate the structure and interrelations of emotions. It is anchored on **two core dimensions: emotional valence and emotional arousal.** Emotional valence refers to whether the emotional experience **is positive or negative subjectively**, while emotional arousal indicates the **intensity or degree of the emotion (Fig 5.2.3).**

In the end of workload record, participants are required to draw a pie chart summarizing their overall emotional feeling of workload (Fig 5.2.4). To provide more descriptive options, Emotion Typology (Fokkinga et al., 2022) are used. It includes 60 emotions, consisting of 20 positive and 40 words. Participants are free to add their own words if none are applicable.

- What are people's perceptions of workload and stress, respectively?
- What kind of notes people will make during recording?

- How do people summarize their record?

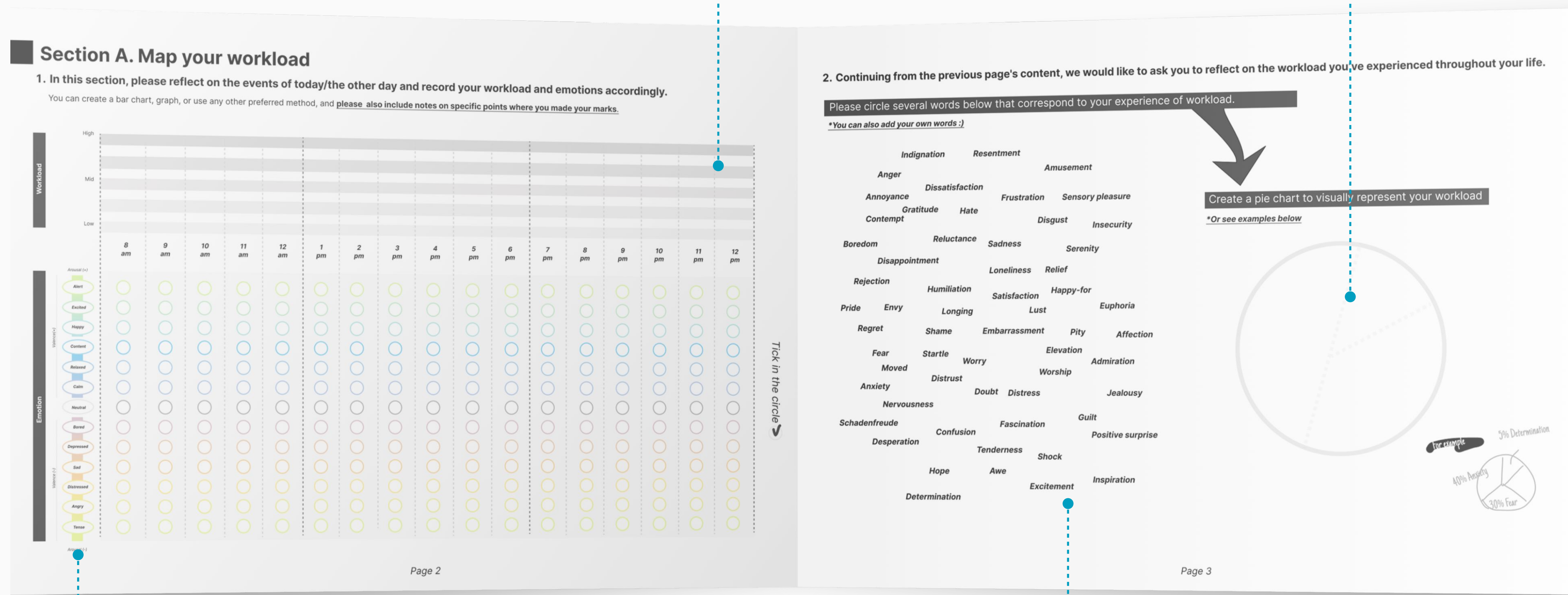
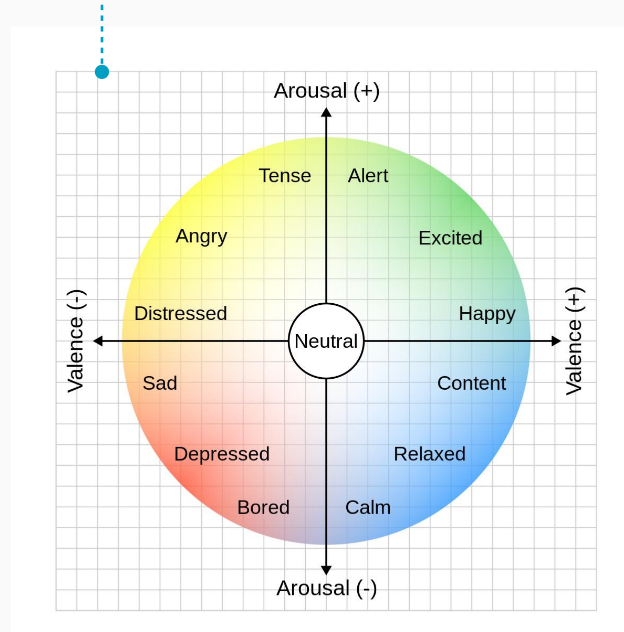


Fig 5.2.2. *Section A in the booklet*



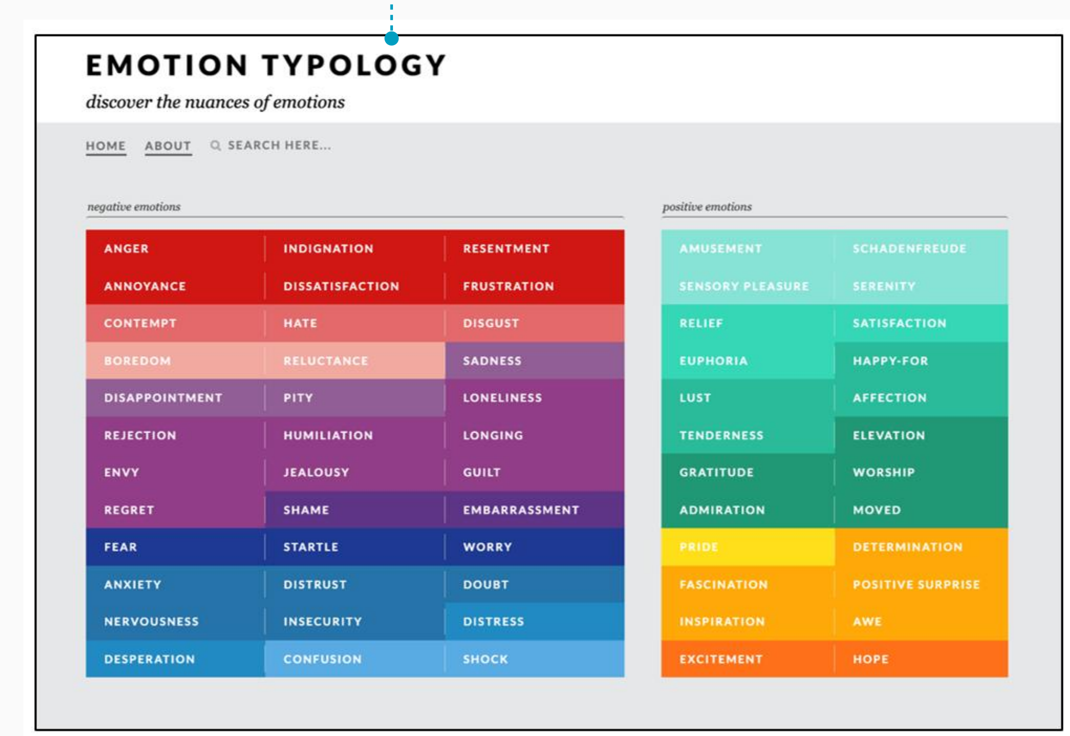


Fig 5.2.3. *The Circumplex model of emotion, (Russell, 1980)*

Fig 5.2.4. *Emotion Typology, (Fokkinga et al., 2022)*

Section B - Stress

Similar to workload record, participants are free to visualize their stress in any visual format. In addition to visualization, participants were required to draw out two or three significant or memorable moments out of their stress record. They are invited to name the level of stress and identify some keywords in these scenarios. Furthermore, similar to the end of Section A, users were asked to create a pie chart to describe their overall emotional feeling of the stress.

- What are people's perceptions of workload and stress, respectively?
- How do people summarize their record?
- How do people define their stress?
- What do people value in their record?

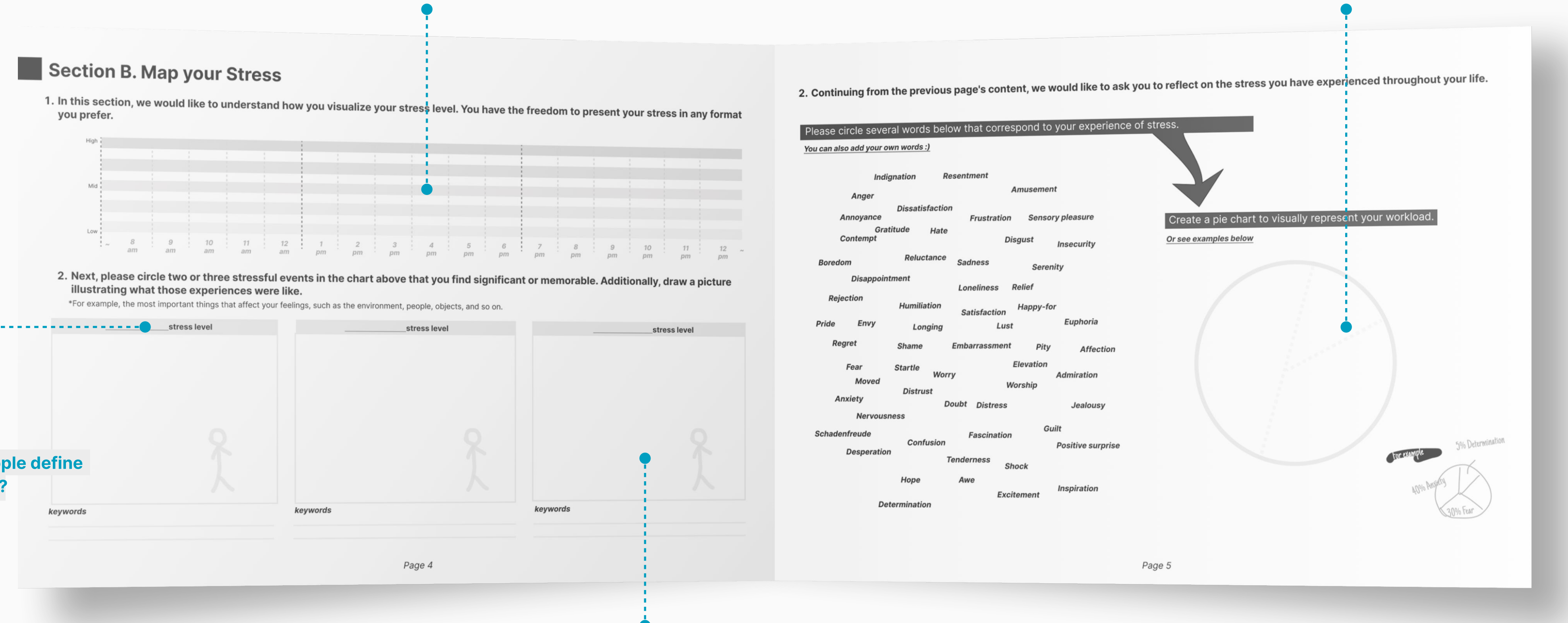


Fig 5.2.3. Section B in the booklet

Section C - Reflections

In Section C, the focus is on understanding participants' perspectives on the overlap between their recorded "workload" and "stress" and why they believe there are similarities and differences between the two. Additionally, participants are invited to note any difficulties or insights they encountered while recording both workload and stress.

- What are people's perceptions of workload and stress, respectively?

Fig 5.2.3. Section C in the booklet

5.3
Results of Survey

The analysis of the survey involves both qualitative and quantitive analysis. The answer of questions listed in Table 5.2.1 are merged into three topics. See Fig 5.3.1.

Topics	**5.3.1 Correlation between Workload, emotion and stress**	**5.3.2 Emotion typologies used**	**5.3.3 Memorable notes**
way of analysis	Statistical Analysis (correlation)	Statistical Description	Qualitative Analysis
Answered questions	• **What are people's perceptions of workload and stress, respectively?** • **How do people define their stress?**	• **How do people summarize their workload and stress?**	• **What kind of notes people will make during recording?** • **What do people value in their record?**

Fig 5.3.1. *Overview of the results of survey*

5.3.1 Correlation between Workload, emotion and stress

Regression analysis between workload, emotion and Stress

To understand the relationship between workload, emotion and stress for users, participants' records are converted into numerical values (Workload and Stress converted to a scale of 1-10, Emotion converted to a scale of 1-13, see Fig 5.3.2), and inputted into SPSS for regression analysis. Emotion is treated as the independent variable (X-axis), and workload as the dependent variable (Y-axis), for conducting regression analysis.

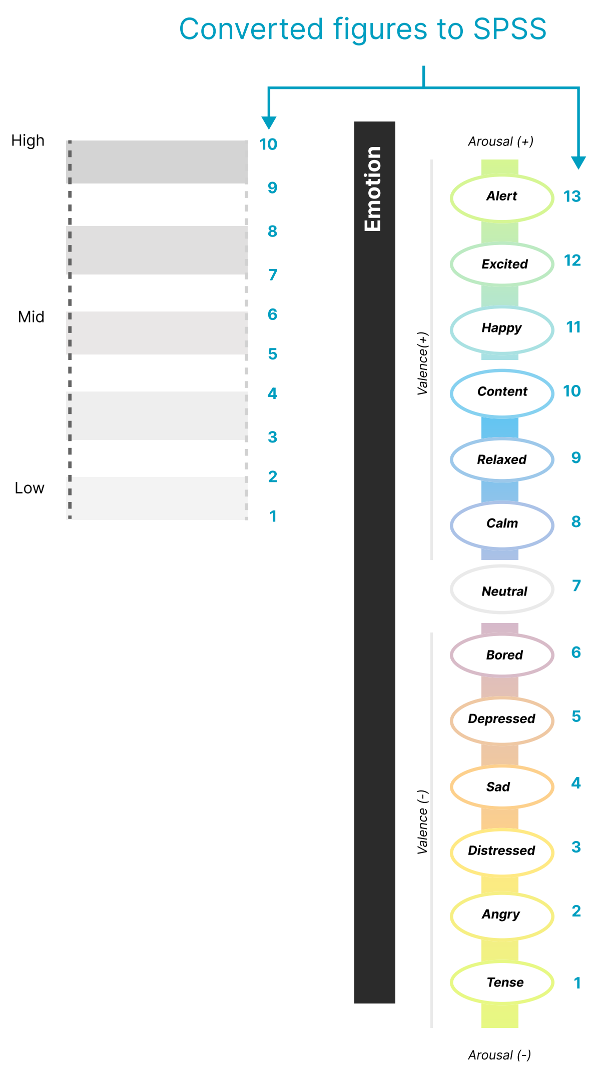


Fig 5.3.2. *Process of converting words into numerical values*

Null hypothesis

In this regression analysis, the primary aim is to verify whether emotion and stress, from the users' perspective, have a significant impact on workload. Therefore, the null hypothesis (H0) is set as follows: Emotion and stress have no significant effect on workload.

Poor explanatory power

The test results, as shown in Table 5.3.1, indicate an R Square value of 0.344. Typically, the R Square value obtained from a regression analysis ranges from 0 to 1, with higher values indicating better explanatory power. According to relevant academic research, a value above 0.5 indicates good explanatory power. However, in this model, the R Square value is 0.344, indicating that emotion and stress can only explain 34% of the variability in workload, which is not high, and 65.6% of the variability in workload is explained by other factors not included in the model.

Table 5.3.1. *Explanatory power*

	R Square	R Square Adjusted
Workload	.344	.336

Stress has a significant impact on workload

However, despite the low explanatory power of the model, the analysis results indicate (see Table 5.3.2 and Fig 5.3.3) that stress has a significant impact on workload (t=8.301 > 2, p value < 0.001), and it is positively correlated (B=0.569). H0 was rejected. In summary, stress is recognised as a key factor in workload, but does not represent all influences.

Table 5.3.2. *Significance Analysis of Path Correlation*

Path			Standardized Beta	t Value	Sig.
Emotion	⟶	Workload	-.026	-.444	
Stress	⟶	Workload	.569	8.301	<.001

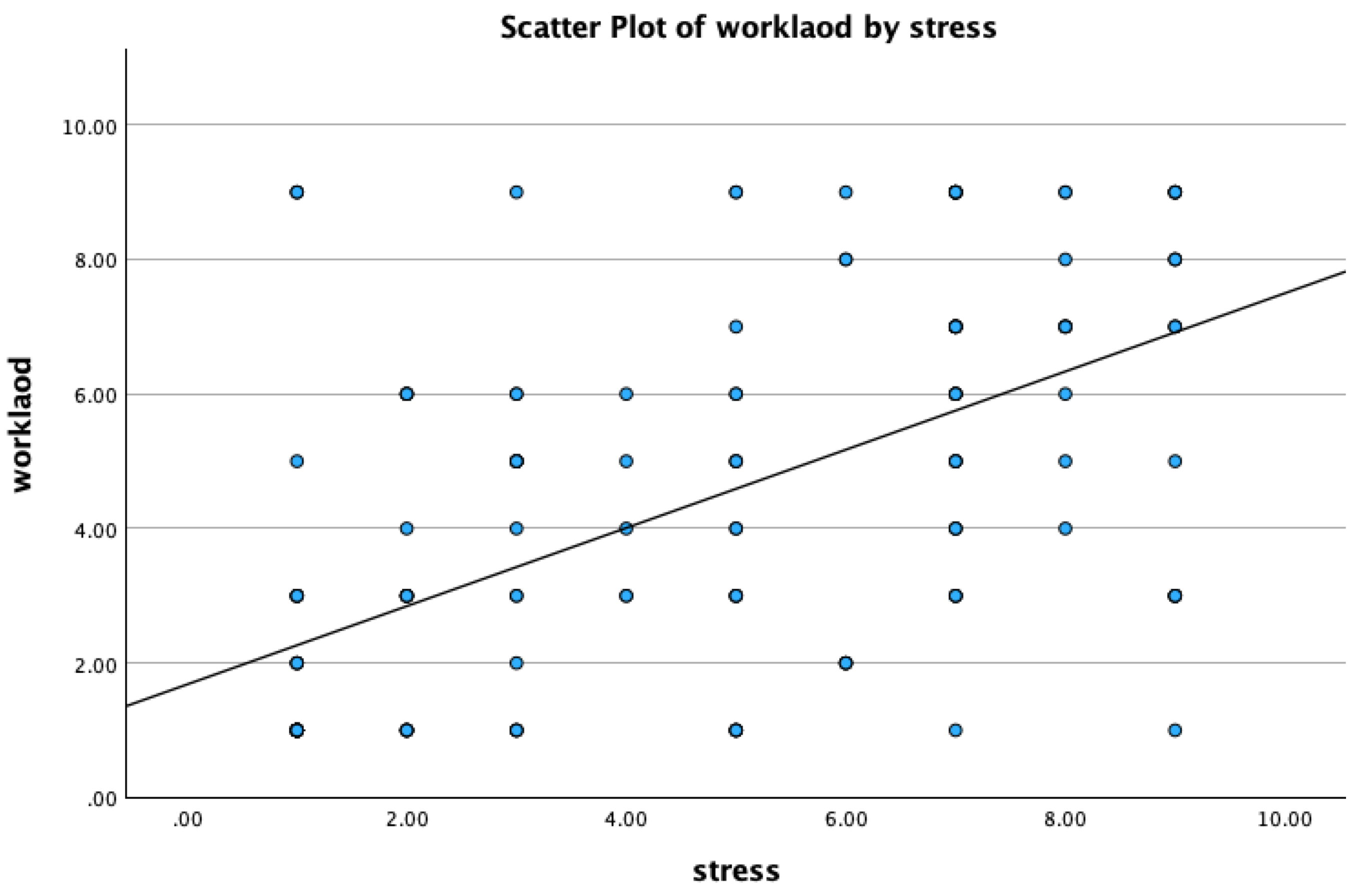


Fig 5.3.3. *Scatter Plort of workload by stress*

Overlap rate between workload and pressure

Drawing from prior research indicating a correlation between stress and workload, this section endeavors to delve into participants' perspectives regarding the degree of overlap between the two and the underlying reasons, as discerned from their records.

Subjective rating on the overlap between workload and stress

A Likert 5-point scale question was included in Section C reflection: "*Overall, to what extent do you feel that your work and emotion records overlap with the results of your stress records?*". Here, respondents could rate their perception on a 5-point scale, with 1 indicating no overlap (0%) and 5 indicating complete overlap (100%).

Rating "5" Overlapped 100%	2/10
Rating "4" Overlapped 75%	3/10
Rating "3" Overlapped 50%	3/10
Rating "2" Overlapped 25%	2/10

Overall results

Overall, among the 10 participants, 2 individuals believe that their stress and workload overlap completely, 3 consider the overlap to be 75%, 3 perceive a 50% overlap, and 2 perceive a 25% overlap (See Fig 5.3.4).

Below are the commonalities and differences between stress and workload, as concluded from participant quotes.

Commonalities: negative emotion

Some participants believe that workload and stress may mutually influence each other, particularly in situations of high workload and stress. They highlight negative emotions as the reason of the correlation, such as anxiety, frustration and worry.

*My workload is driven by stress and emotion (**B6**)*

Workload 80% contributes to my stress level, especially when feeling anxious, distressed, worry (***B1***)

Differences: positive emotion and quantifiability

Conversely, other participants believe that there are big differences between the two, lies in "positive emotions" and "quantifiability." Participants note that workload doesn't always lead to negative emotions, and workload is easier to quantify compared to stress.

*Proper workload can contribute to more positive emotional response, when I feel I am capable of deeling with it (**B1**)*

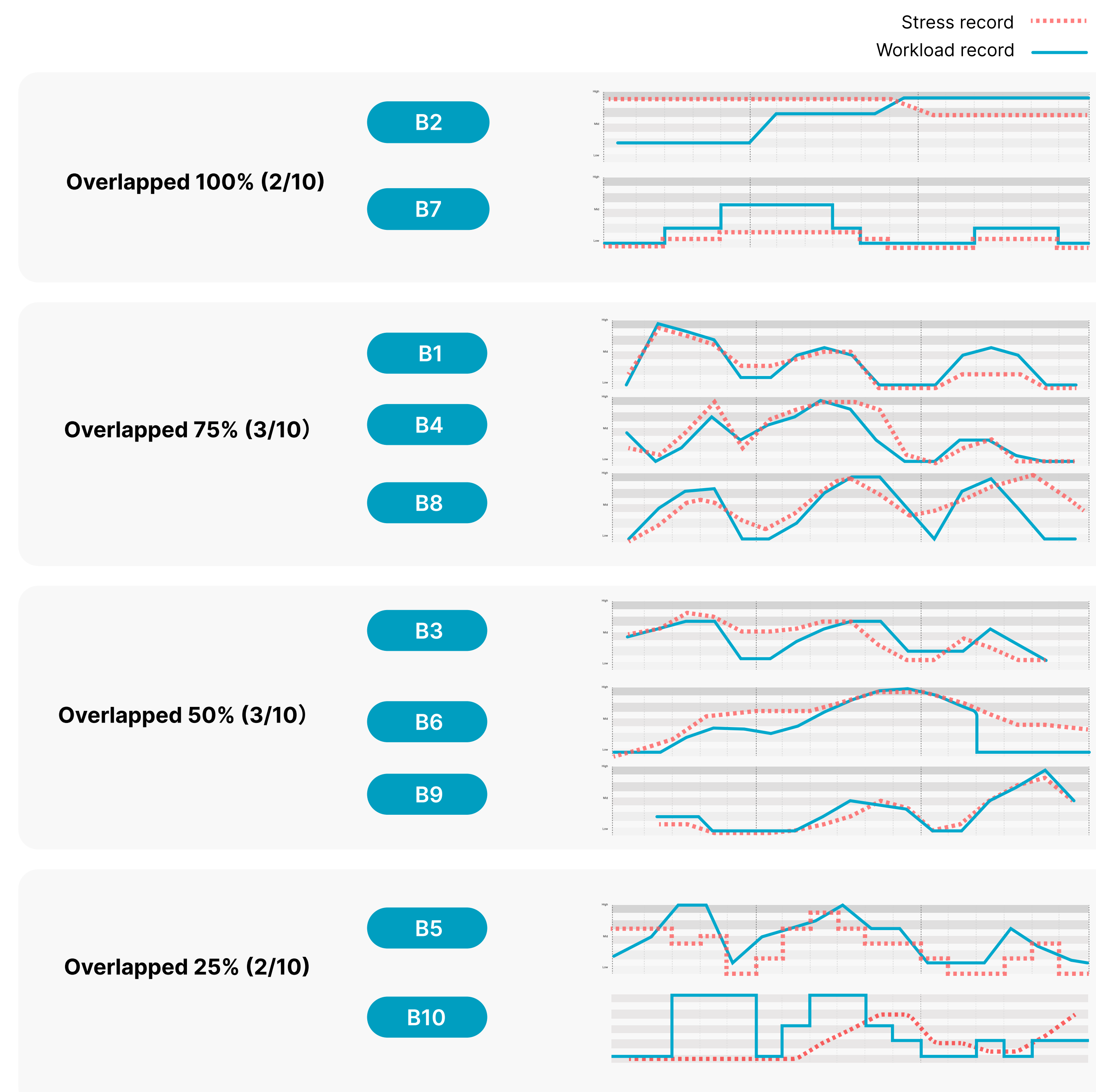


Fig 5.3.4. *Overall results of Subjective rating on the overlap between workload and stress*

5.3.2 Emotion Typology used

Overview

Building on the previous analysis, the findings reveal that the distinctions and commonalities between workload and stress both refer to emotions. In this section, the research further utilize the analysis of emotion typology to explore what emotions specifically entail for users.

The overall results show that 38% of the words used to describe workload are positive, while all (100%) of the words used to describe stress are negative, as shown in Fig 5.3.5 and Fig 5.3.6. Initial responses can be found in Appendix D.

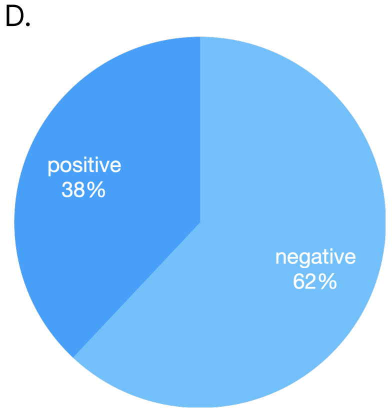


Fig 5.3.5. *Words used to describe workload*

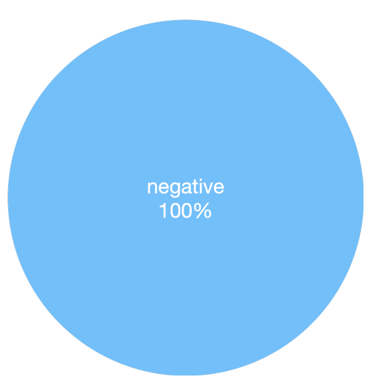


Fig 5.3.6. *Words used to describe stress*

Furthermore, as depicted in Table 5.3.3, there is significant overlap in the negative words used for workload and stress, with 11 of the same words appearing in both categories.

Table 5.3.3. *Overview of words used for workload &stress*

Workload		Stress
Positive	Negative	
Happy-for	Annoyance	
Gratitude	Anxiety	
Serenity	Boredom	
Moved	disappointment	
Achievement	Dissatisfaction	
Inspiration	Doubt	
Hope	Frustration	
Positive surprise	Guilt	
Pride	Self-abandoned	
Determination	Self-hatred	
Excitement	Worry	
Satisfaction	Nervousness	Insecurity
	Reluctance	Confusion
		Distress
		Embarrassment
		Fear
		loneliness
		Nervous
		Regret
		Shame

Negative words used in Workload & Stress

As shown in Fig 5.3.7, among the negative words used to describe workload and stress, "**Anxiety**" was mentioned most frequently by participants (workload 7/10, stress 8/10). It is also considered as the highest proportion of emotion attributed to workload (26%) and stress (77%). This indicates that people usually experience anxiety while working or feeling stress.

According to Fokkinga et al. (2022), The definition of **"Anxiety"** refers to

"The feeling when you think about bad things that could happen to you. You are on guard, because you don't know what the threat is." -Anxiety

When in a state of anxiety, the brain processes a large amount of information subconsciously, but cognitive efficiency is not high because it's often unclear where the threat is coming from or why it's occurring.

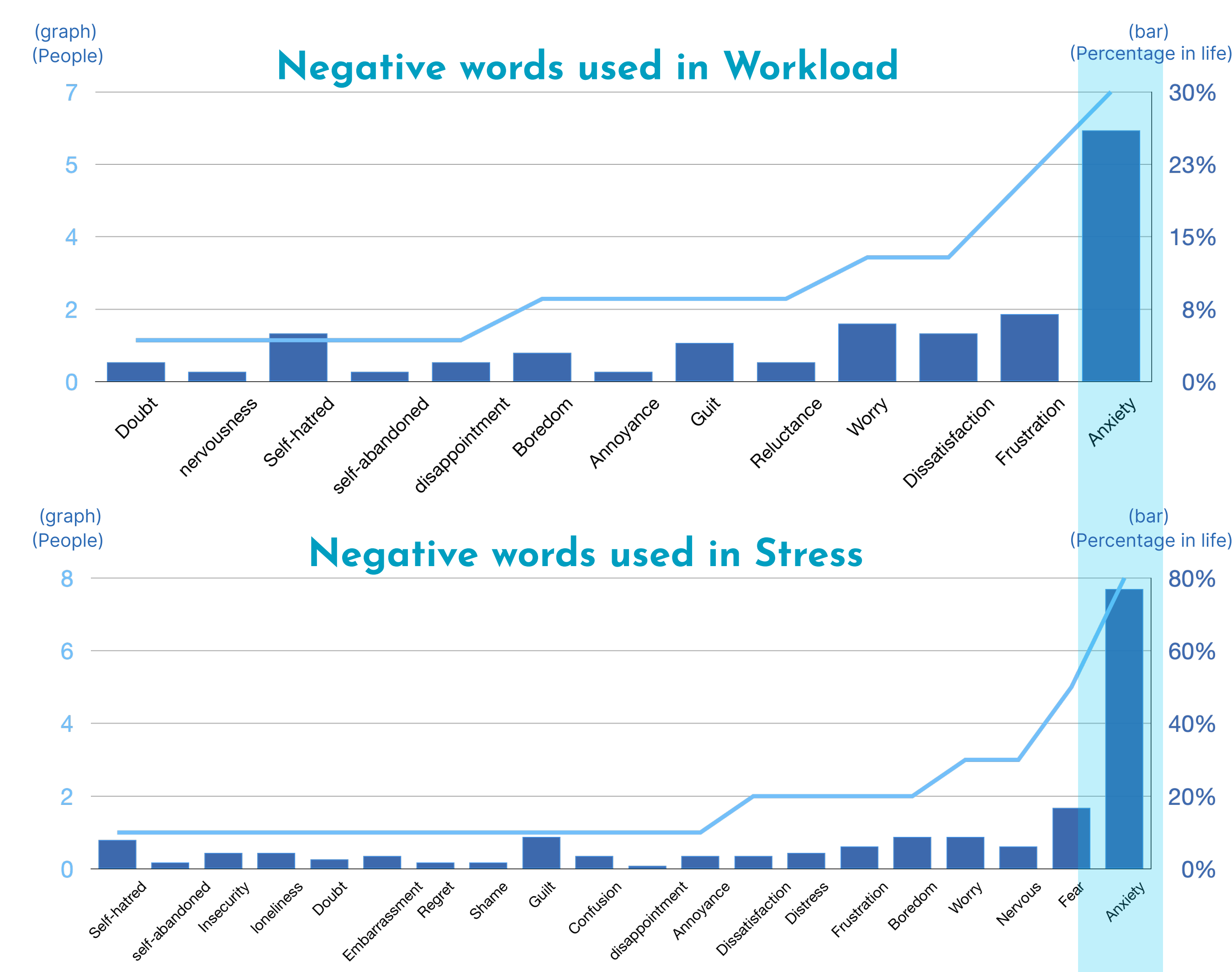


Fig 5.3.7. *bar chart of negative words used for workload and stress*

Podiyive words used in Workload

As shown in Fig 5.3.8, the term "Satisfaction" was mentioned by the most people (5/10). According to Fokkinga et al. (2022)'s definition, "Satisfaction" refers to

“The feeling when something meets or exceeds your expectation.” -Satisfaction

However, people perceive "Excitement" to be the most prevalent positive emotion in workload (11%). Its definition is

“The feeling when you expect something good or nice will happen to you. You cannot wait for it to happen.” -Excitement

It appears that for most people, what leaves the most profound impression regarding positive workload is experiencing a sense of satisfaction, although this isn't always the case. In contrast, the majority of positive workload experiences in life are often characterized by a sense of excitement about anticipating good things to happen.

Commonalities: waiting

From participants' descriptions, it appears that when experiencing workload and stress, whether it's positive or negative emotions, users are often in a state of "anticipation." The anticipation of long-term outcomes may lead to negative anxiety or positive excitement. This suggests that the source of negative emotions for people may not necessarily lie in the nature of the work itself, but rather in the element of time.

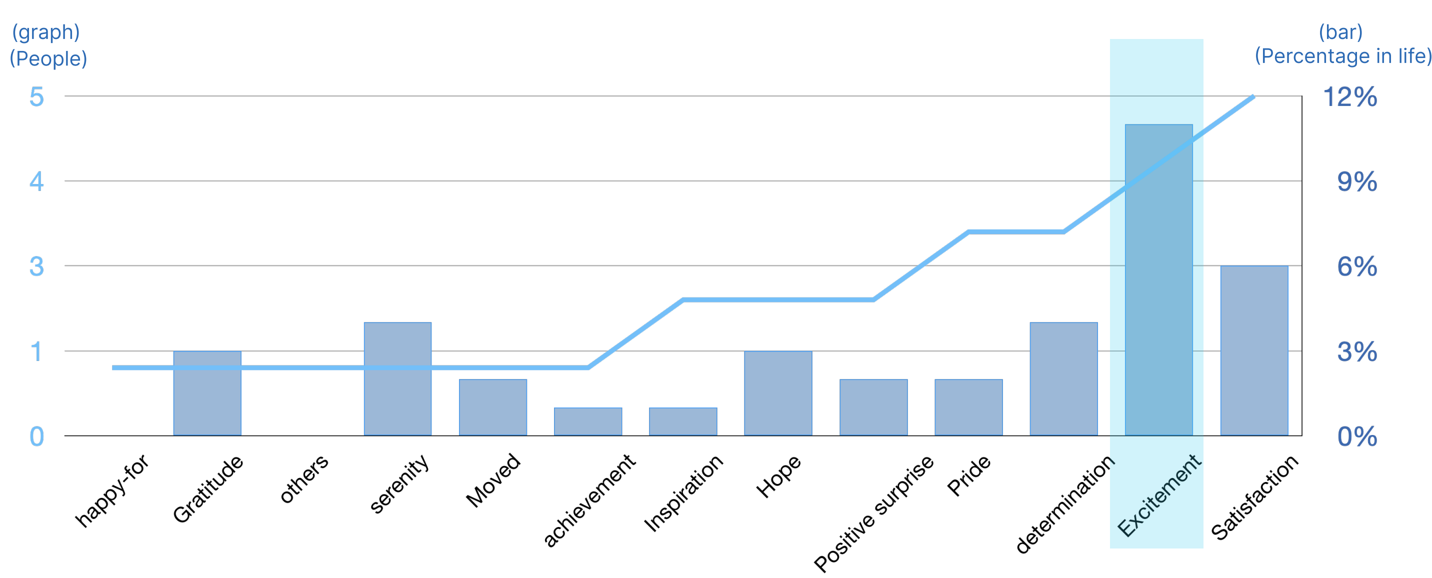


Fig 5.3.8. *bar chart of positive words used for workload*

5.3.3. Memorable notes

Returning to the initial exploration of the differences between workload and stress as perceived by users, in contrast to the previous sections where we analyzed emotions, this section will primarily delve into the events recorded by participants. This includes exploring the differences in the events recorded by participants for workload and stress, as well as considering potential influencing factors.

Workload events

When recording workload, participants are encouraged to mark significant or memorable events that occurred during their workload tracking. A s shown in Fig 5.3.9, Six out of ten participants made annotations.

Common memorable lowest point- Eating

If observe the event markers left by participants in their workload records, 6 out of 10 participants include records of "breakfast, lunch, dinner." These marks appear in the lowest workload area, almost like three breakpoints of the day. That is, eating might be universally acknowledged as the lowest workload point for people, thus serving as the most memorable low point in workload tracking.

In the Same Task: Fluctuating versus Consistent Workload Levels

From the participants' drawing styles, we can generally observe two main approaches. One is a continuous line graph with many turns, while the other consists of several flat segments forming a staircase pattern. For some individuals, workload fluctuates constantly (e.g., B4, B5), while for others, workload remains relatively constant within a given period (e.g., B2, B7). This reflects two different perspectives: some believe workload is constantly changing, while others perceive workload as being stable within a single task.

Focusing on Extreme Values or Average Values

From the participants' annotated positions, four participants marked the lowest or highest points, while 2 participants marked within the range. This raises a question: Are people's most memorable moments the ones with the strongest feelings, or are they the composite feelings that have been sustained for a period of time?

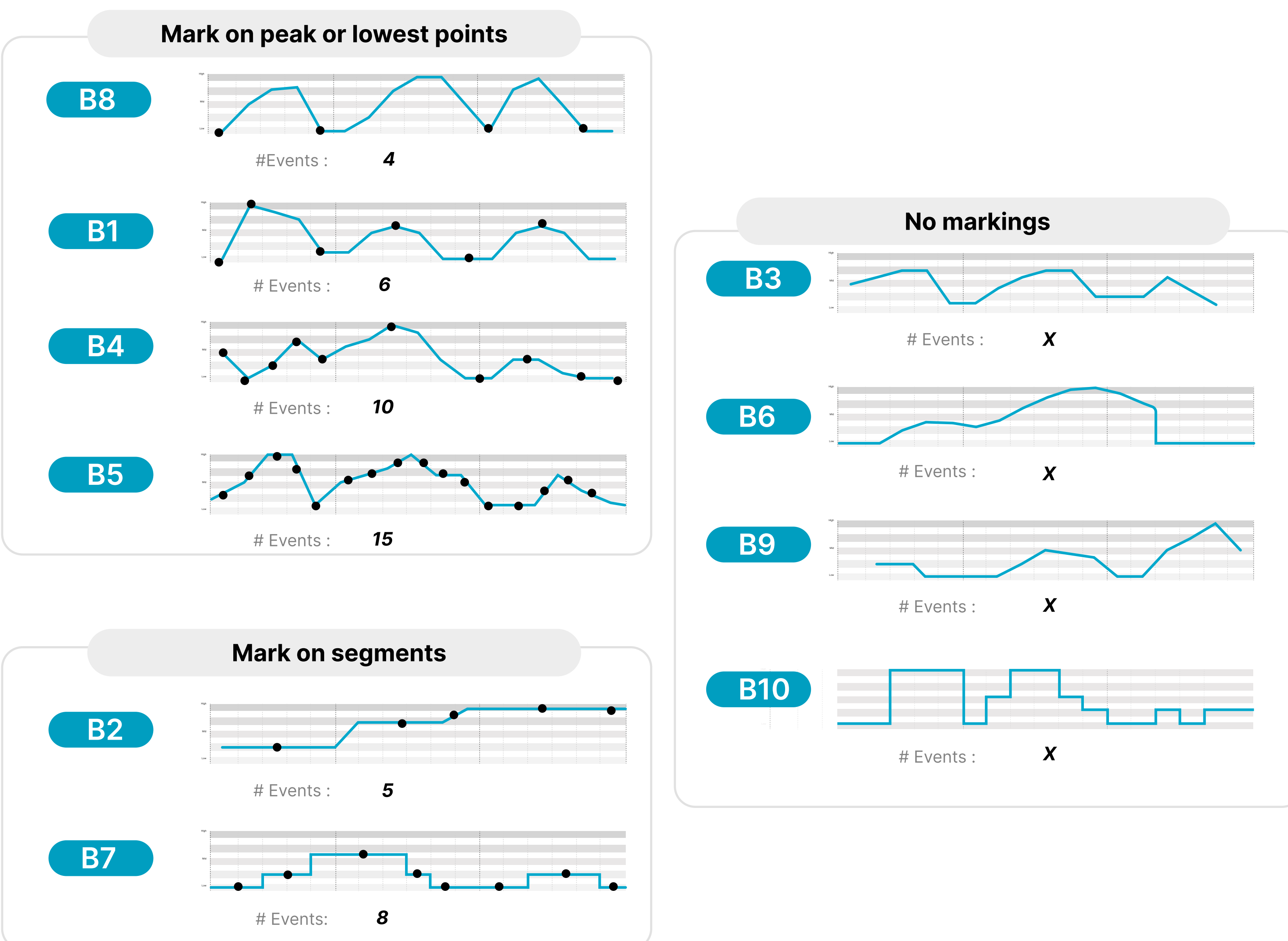


Fig 5.3.9. *Illustration of marks on workload record*

Stress events

After recording stress, participants are asked to select two to three memorable time points and indicate, either through drawing or writing, the sources and key factors that contributed to this stress. In terms of results, there are three main themes observed to influence perceptions of stress level.

Other ways to describe stress levels besides 'high stress' : Time

Interestingly, different participants use varying terminology to describe memorable stress levels. While the majority (8 out of 10) still focus on describing "High" stress levels, there are different naming conventions observed. For instance, one participant used time-based descriptors such as "Morning stress level" and "Afternoon stress level," while the other focused on the magnitude of stress variations with terms like "Increasing stress level" and "Continuous stress level." Additionally, there are two participants who combine low and medium stress levels together, as seen in the naming convention "Low-Mid stress level." This suggests that categorizing stress into high, medium, and low levels may have some ambiguity for users , and "time" might be a more meaningful way for users to classify stress.

Popular keywords: plan and communication

After analyzing the keywords, two high-frequency themes emerged: "planning" and "communication." Firstly, regardless of whether it's associated with high stress levels, many participants described the most memorable stress coming from planning rather than the tasks themselves. Keywords related to this theme include: plan, time management, to-dos, wasting time, efficiency, Tasks that are never-ending.

 # Plan (x1),
 # Time management (x2),
 # To-dos (x1),
 # Behind schedule (x1),
 # Wasting time (x1),
 # Efficiency(x1),
 # Tasks that are never-ending(x1)

Fig 5.3.10. *A respondent drew stress centered around plans*

Another theme revolves around people. Related keywords include people, discussion, communication, and similar terms. Interestingly, when describing low stress levels, many participants specifically mention that being "alone" or "solitude" is a relatively low-stress situation. These keyword records indicate that people may be one of the important factors influencing stress.

> *#Communication (x2)*
> *#People(x3)*
> *#Group discussion(x3)*

Fig 5.3.11. *A respondent drew stress centered around communications*

5.4 Conclusion of Survey

Takeaways of survey record

- Many people believe their workload and stress are closely linked. However, statistical findings show that while stress is indeed correlated with workload, its direct impact on workload is limited.

- Emotion is the key factor for people to distinguish between workload and stress. Many believe workload doesn't always lead to negative emotions like stress does.

- People's perception of time may play a significant role in influencing both workload and stress. The most commonly used terms in research to describe workload and stress are "Anxiety" and "Excitement". According to the definitions of these two terms, it is evident that people's most profound impressions of workload and stress occur when waiting for positive or negative events happen. On the other words, an accumulated emotional response from prolonged waiting compose the major impression of workload and stress.

- "Time management" emerge as crucial aspects where design interventions can intervene and aid individuals in making necessary cognitive adjustments.

Chapter 06

Conclusion

6.0

This chapter concludes the key findings from previous research. Following the research conclusion, discussions about various research aspects and recommendations for future design are presented as the culmination of this research project.

6.1 Conclusion

6.2 Recommendations for future design

6.3 Discussion

6.1 Conclusion

Summary

Referring back to the initial purpose of this research, which is to bridge the gap between traditional methods of measuring mental workload and the utilization of wearable neurotechnology for measuring mental workload, three research questions were established at the very beginning of the research:

RQ1.
What do people understand Mental Workload in terms of this terms and the outcome of this technology?

RQ2.
How to motivate people to self-track their Mental workload through this technology?

RQ3.
What are the user needs when self-tracking Mental workload?

RQ1

Regarding the first research question, exploratory interviews revealed that users often misunderstand mental workload, often equating it with emotional or cognitive stress rather than considering its relation to cognitive resources and task suitability. This confusion may stem from the complexity of the term "MWL" or a lack of awareness that brain performance can be measured. Additionally, both the results of interviews and survey records indicated that people intuitively perceive the tracking device as measuring stress, showing difficulty distinguishing workload from stress. However, they showed little interest or perceived usefulness in the "stress value" results. In addition, post-test insights emphasized that many terms and cognitive data combinations are not easily understood by users, highlighting the need for clearer explanation and understanding. For instances, users do not actually understand metrics like "Moderate" or "Disengaged" in EMOTIV's current design.

RQ2

The second question concerns how self-tracking behaviors of MWL are formed, including exploring motivations. This study approached this from various research methods and perspectives. Firstly, through exploratory interviews, we discovered various perceived barriers to MWL self-tracking, such as skepticism, mistrust, misunderstanding, or indifference towards cognitive data. During the user tests, we found that some concerns, like skepticism or mistrust, were not as significant. However, issues like not understanding the meanings of terms or the significance of tracking these data had a significant impact on tracking motivations. Survey results also showed subjective and unique records and understanding for each participants, with performance or time-related metrics being the most valued and comprehensible motivations for tracking. Particularly, data related to time management seemed to be better understood and valued by users, serving as a stronger motivation for tracking.

RQ3

The third research question is somewhat similar to the second one, but their main difference lies in RQ2 focusing on users' triggers before interacting with the product, while RQ3 explores needs during and after using the product. When people start tracking data, what should they pay attention to? Are there any extended needs? Insights for this part mainly come from the results of user tests, where we found that users' expectations regarding tracking results lie more in the process than the outcome. For instance, people are not concerned about whether they are "too stressed," but rather "why they are feeling stressed." They don't want to be "told how to change their cognitive state," but rather "explore the reasons themselves and decide how to improve." They are not aiming to know their state "in the moment of a task," but rather view the data as a "tool for improving work processes" for afterwards reflections or re-scheduling. These insights might be categorized as users' unique perceptions of cognitive data.

Conclude with the theory

To consolidate the insights from earlier chapters, conclusions will be aslo summarized based on Li et al.'s (2010) MWL self-tracking model.

Preparation Stage

In terms of the preparation stage, this research focuses on exploring users' understanding and motivation for tracking MWL. From the literature review in the first chapter, it was indicated that both the definition and measurements of workload and MWL are not fixed. Therefore, through interviews with participants in the second chapter, definition and motivations for tracking MWL were explored, uncovering various issues that might lead people to reject MWL tracking. These issues include misconceptions about MWL equating to stress status, distrust in cognitive data, and inability to see the significance of tracking this data in their lives. These issues were addressed by exploring potential solutions in the literature, such as adding meaning to MWL tracking (e.g., avoiding prolonged states), understanding people's beliefs about data accuracy, and designing data that promotes reflection. However, after validating these potential solutions through design in the fourth chapter, some results contradicted the findings from the earlier interviews.

- Users initially wanted to see the impact of data and receive specific improvement suggestions, but this conflicted during testing. Testing results showed that people prefer not to be told how their brains should work.
- Most users prefer to explore the meaning of data themselves rather than receiving direct answers, even if they may not find a standard solution.
- Users are more interested in their work performance rather than cognitive indicators like focus scores.
- They are interested in aspects such as time management and improving task completion rather than understanding their current cognitive state.
- Data accuracy was a significant concern during interviews but was not raised during testing.
- While verifying device accuracy motivated many users, none questioned the data; they were convinced by data immediately.
- Although users suggested various tracking functionalities in interviews, during testing, they preferred focusing solely on explaining data trends, which attracts them most.

Collecting Stage

In the literature review, the collecting stage has typically been conducted in controlled environments in the past. However, when applied to everyday life, we must consider various influencing factors, including the wearing experience of the device and the duration of device usage. These factors affect users' perception of data accuracy and their willingness to use it. From the interviews in the first stage, we mainly learned that most people anticipate feelings of boredom during data collection and perceive the anticipated outcomes as singular (for example, expecting results only to indicate whether they are stressed). However, during the validation stage, we discovered:

- During the data collection period, users typically don't feel much about the product. Due to their focus on work, they don't pay much attention to the data either.
- Users are willing to wear the device for a limited time, depending on their attention span (up to 2 hours at most). In other words, people are willing to wear the device primarily to improve their cognitive state. Wearing such a device during leisure time may bring stress instead.
- During the data collection phase (while working), people don't frequently check the data and don't want to see too much information.

Integration Stage

At this stage, the focus is on turning data into insightful information. While literature shows brainwave technologies can explain aspects like focus and stress, initial interviews reveal existing product's ,metrics, especially derived metrics, are not intuitive for users. Thus, in the validation stage, the research tried to improve it by adding features like visualizing derived metrics or design an "adjust status" function to help users better understand derived metrics. However, research results showed:

- These derived metrics still aren't correctly understood by users. In contrast, people show greater understanding on raw metrics, like cognitive stress metric.
- Derived metrics are like grading cognitive conditions for individuals, which is strange for users. This skepticism arises from doubts about the basis of the standard line and how to ensure that each person is judged using the same comparison standard.
- Compared to derived metrics, most people favor analyzing raw metrics. During the data integration phase, users seek to make comparisons of cognitive data more tangible, rather than altering the data design itself.

Reflection & Action Stage

According to the results of the first interviews, people value the timing and outcomes of reflection. Not everyone may take action eventually, but the insights gained during this phase may influence whether individuals are willing to track cognitive data again in the future. The research findings indicate:

- Many users express uncertainty about how their cognitive data can impact their lives. Some point out that significant changes may not be noticeable in the short term, while long-term data lacks discernibility. Therefore, presenting data in chronological order makes it challenging for users to reflect or take action.
- Customized recording is a demand raised by many participants. Because there isn't just one way to measure workload and MWL, according to the literature, it could be based on time spent, task difficulty, or workload itself. Since each person aims to improve different aspects, customized recording methods can better assist users in organizing data and facilitating reflection.
- The purpose and form of reflection vary from person to person. Some seek to improve performance, while others may simply want to understand the trend of their cognitive changes. Depending on the form of reflection, the required data and information also differ. For example, several participants suggest distinguishing the amount of information between reviewing data during and after tasks. Data during tasks may need to avoid inducing negative emotions and be concise, while post-task information should facilitate reflection.

Main insights from Phase I

phase I Insights from literature review

phase I Insights from interivew

phase I~II Insights from literature review

Stages	Preparation	Collecting	Integration	Reflection	Action
Behavior	Thinking of tracking MWL data and decide to start tracking	Wear the device and start tracking	Convert data to reflective information (can be done by system)	Look at data and Reflecting on it	Making changes or Maintaining the status quo

There are various understandings and measurements of Workload and MWL among individuals

The measurement of MWL is subjective ,compared to measuring workload, as it may be influenced by different contextual factors, which are usually uncontroallable and unpredictable.

Current devices can tell several cognitive status through EEG data

Interview question: What do people define Workload & MWL

Interview question: How do people draw their daily MWL

Interview question: What are users' perspectives on the MWL metrics

Interview question: What do people reflect on daily Workload & MWL

Users should not be constrained by their understanding of "stress" but should instead be able to comprehend the relationship and mutual influence between cognitive data and daily life.

Stress, but not merely stress: value stress but interpret it well with MWL

Making people acknowledge cognitive data may be a challenge.

Resonating with the cognitive data: build users' trust on data

Users should perceive that they can gain new insights from the data and that the tracking process holds reflective value.

Enhance the connection: emphasize data's impact on people's lfe

Providing users with appropriate information and functionality at different time points are another key focus in designing cognitive data trackers.

Providing right information at right times: reduce negative experience

As people's acceptance and understanding of tracking cognitive data remain limited, there is a need to dive deeper into how the data is presented

More than data: help users develop understanding or interacting with data in a different way

No judgement on MWL's performance
Sustainment is the main issues
Entering ideal status may be a difficulty

Stress is kind of **intense negative** response to MWL, and is kind of **warning sign** of poor cognitive resource allocation.

Allowing the user to **calibrate data or set their own objective**
Support for **Testability**

If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users

Segmenting information , Provide **Medium level of data abstraction**

Allowing the user to **build up a personalized historical data**

Using **Metaphorical abstraction** to stimulate reflection in the user

To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive, such as help relax.**

Fig 6.1.1. Main insights from Phase I

Main insights from Phase II

phase I~II Insights from literature review

Phase II Insights from User test

Phase II Insights from Survey

Stages	Preparation	Collecting	Integration	Reflection	Action
Behavior	Thinking of tracking MWL data and decide to start tracking	Wear the device and start tracking	Convert data to reflective information (can be done by system)	Look at data and Reflecting on it	Making changes or Maintaining the status quo

No judgement on MWL's performance
Sustainment is the main issues
Entering ideal status may be a difficulty

Stress is kind of **intense negative** response to MWL, and is kind of **warning sign** of poor cognitive resource allocation.

Allowing the user to **calibrate data or set their own objective**

Support for **Testability**

If accuracy issues can not be solved, presenting **trueness of trend** can be another way to convince users

Segmenting information , Provide **Medium level of data abstraction**

Allowing the user to **build up a personalized historical data**

Using **Metaphorical abstraction** to stimulate reflection in the user

To coping with **uncontrollable stressors, emotion-focused strategies are most adaptive, such as help relax**.

Most people utilize cognitive data after tasks for critical reflection, confirming changes, rescheduling and making adjustments.

Most people check and reflect on data after tasks instead of during the task

For passive users, notifications serve as their sole means of access to the data.

Ideal state and suggestions are not necessary for users as these information are considered to be too personal to trust.

When it comes to cognitive performance, people do not want to be told what to change, which may make them feel offensive and meaningless.

Tracking data is an inconspicuous experience, as its wearing sensation is similar to that of wearing headphones.

Instead of suggestions or adjustment guide, people prefer to explore the reasons of poor cognitive performances. Exploring something they do not know values more than data accuracy. To achieve so, users are even willing to provide with more data.

Many individuals do not expect to wear tracking devices for long periods, often limited by their ability to maintain focus.

Users desire more functions enabling them to personalize their own data library.

Users expect this app to specialize in displaying cognitive data. While users don't anticipate perfect data accuracy, mere numerical changes can already convince them. However, users require more guidance on how to interpret graphs or metrics.

Timeline serves as critical elements for users. Different time points and time interval can provides different levels of information.

Many people believe their workload and stress are closely linked. However, statistical findings show that while stress is indeed correlated with workload, its direct impact on workload is limited.

Emotion is the key factor for people to distinguish between workload and stress. Many believe workload doesn't always lead to negative emotions like stress does.

An accumulated emotional response from prolonged waiting compose the major impression of workload and stress.

"Time management" emerge as crucial aspects where design interventions can intervene and aid individuals in making necessary cognitive adjustments.

Fig 6.1.2. *Main insights from Phase II*

6.2
Recommendations for future design

Based on the previous research findings, there are 3 types of design concerns and 11 design recommendations for the future as follows:

Presenting cognitive data

1. The importance of dynamically displaying changes in data

Although we still cannot guarantee the precision of data, through design, we can instill trust in users regarding the data. By continuously displaying dynamic changes, users can feel that their brainwaves are indeed being detected as they change. Compared to static indicators, this dynamic presentation can provide users with a greater sense of trust. (Fig 6.2.1)

2. Simplify into two main interfaces / functions

Distinguish between interfaces for "During task" and "After task" purposes, where the former is primarily for real-time monitoring, and the latter is for comparison. (Fig 6.2.2)

3. Timeline

Limit the timeline to two hours at most, with hours as units, considering the typical attention span limit of individuals. (Fig 6.2.3)

4. Be careful of the terms used to describe cognitive data

Suggest to visualize metrics rather than explain with words. Because some words used to describe cognitive data may be difficult for users to understand. For example, 'Saved' is easily understood in other apps, but may not be intuitive when describing cognitive data.

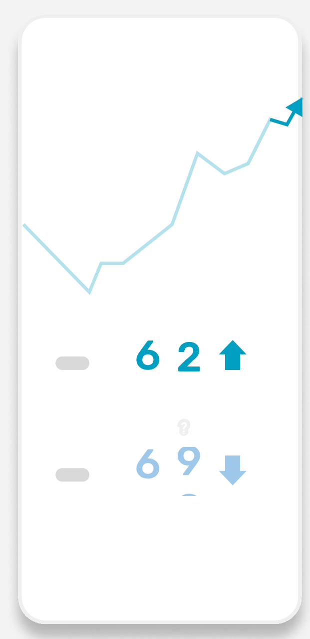


Fig 6.2.1 Illustration of Dynamically display changes

Fig 6.2.2 Illustration of Simplify into two main interfaces / functions, the left one for confirm current status, the right one for making comparisons

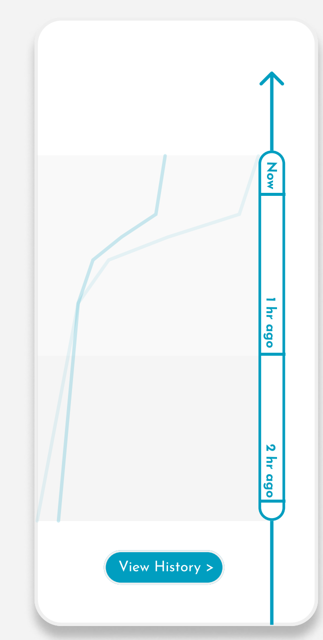


Fig 6.2.3 Illustration of Timeline

Explain cognitive data

5. Utilize two or more raw metrics

Using two or more raw metrics provides more explanation and exploration opportunities compared to explaining a single term.

6. Explain the balance between different metrics

Provide more emphasis on illustrating the balance relationship between raw metrics to explain workload and offer an explanation of the relationship between the two metrics. (Fig 6.2.5)

7. Explain the trend changes over a period of time rather than the state at a single point in time

For users seeking to improve their cognitive performance, understanding the state at a single point in time, such as knowing that the current stress level is 80, may not be very helpful. It is suggested to explain the trend changes over a period of time, as it is more beneficial for users.

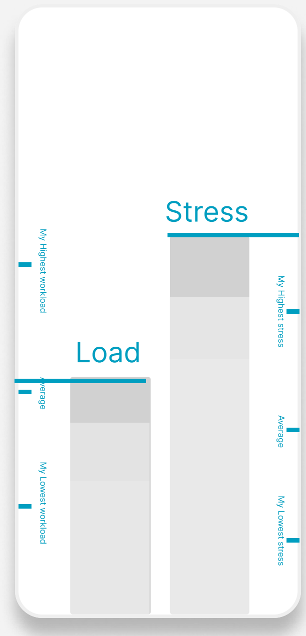


Fig 6.2.4 *Illustration of Comparing with oneself*

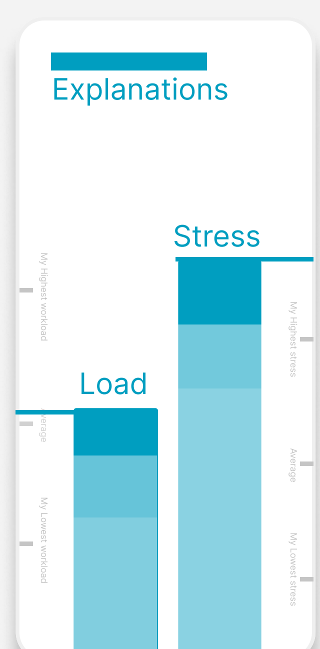


Fig 6.2.5 *Illustration of Explaining the balance between different metrics*

Enhance exploratory nature

8. Comparing with oneself

Suggest labeling the user's historical records, such as "My highest stress/workload," to allow users to clearly perceive their own state changes rather than comparing with the general population. (Fig 6.2.4)

9. Customize labels for comparison

Allow users to label records for "periods of time" to use for comparison in their historical records. (Fig 6.2.6)

10. Incorporate scheduling functionality

Perhaps in the future, integration with scheduling functionality could be considered, providing users with recommendations for optimal scheduling based on past performance with task content.

11. Checklist of factors that may affect workload

Taking inspiration from period tracking apps, perhaps in the future, users could be provided with a checklist of factors that may affect workload performance for their review. (Fig 6.2.7)

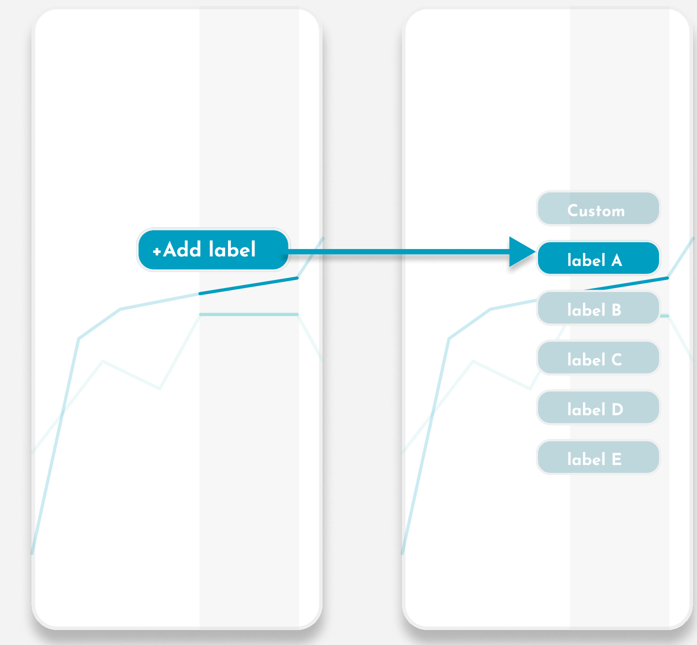


Fig 6.2.6 *Illustration of Customize labels for comparison*

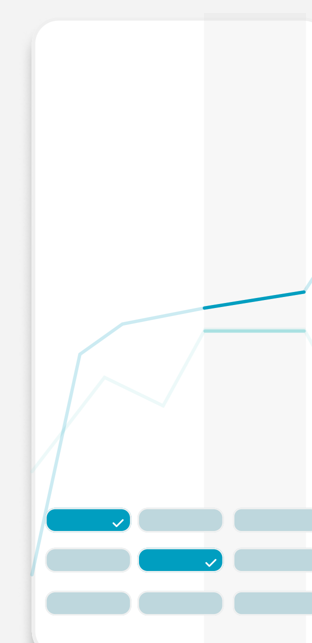


Fig 6.2.7 *Illustration of Checklists of factors that may affect workload*

6.3 Discussion

✓ The results are consistent with the findings of related works.

✗ The results contradict the findings of related works.

Clash: MWL, equal to stress?

Do we need stress indicator as a cognitive metric?

Firstly, regarding the how people understanding MWL, in chapter two's exploratory interviews we found that people held negative attitude on cognitive data and technology due to lack of understanding, connection and trust. During the user test, it is verified that the lack of imagination from users' perspective was observed. Due to limited understanding, many people tend to associate MWL with stress. However, here arises a clash between user perception and the definition of MWL.

From the literature review, MWL is defined as exploring the balance of cognitive resource allocation, while stress is a strong emotional response to unreasonable cognitive resource allocation (Lazarus et al., 1984). Hence, stress can be considered a warning sign of poor MWL. However, from the interview results, people did not emphasize cognitive resource allocation issues when describing stress. Instead, they focused on discussing the results of high MWL causing stress for them.

✗ ***When describing stress, people seemed to be describing a known "result" rather than a resource balancing process.***

This contradicts the original intention of tracking MWL. Therefore, people believe that cognitive data is "known" and tracking it can not change the status quo.

In the booklet analysis in Chapter 5, it was found that people only experience negative emotions when stressed. Hence, many people express a desire to improve stress. However, the reasons for triggering stress vary from person to person. Is it always due to unreasonable cognitive resource allocation? Or is it because of insufficient time? Or perhaps simply because of low stress tolerance? Is it reasonable to equate stress with poor MWL? I believe it is not reasonable because poor MWL may be adjustable, whereas stress may be a highly individualized psychological response that is difficult to adjust. If equated, when stress cannot be improved, people's trust in brainwave detection will decrease. It can be argued that when stress indicators are used as one of cognitive metrics, people's imagination may be restricted, leading to misunderstandings about the significance of tracking MWL.

However, besides stress, can cognitive states really be quantified?

Do we need cognitive metric?

In this PI self-tracking context, quantification is a crucial concept. Therefore, in many self-tracking devices, data and metrics are indispensable elements, symbolizing numerical facts. However, when we associate the concept of quantification with psychological data, many people express that they never imagined their mental state could be quantified. This was discovered to be a significant issue during the later stages of design validation.

Some participants questioned how such subjective things (cognitive performance) can be quantified and translated into a metric.

✓ ***And yes, it is really subjective to judge one's MWL and Stress.***

Aligned with Lysaght et al. (1989)'s three definitions of workload—actual work quantity, time spent on tasks, and subjective psychological experiences—and Mechkati et al. (1992)'s proposition, there are three types of MWL measurement methods: performance-based, perceived effort-based, and physiological activation-based. Throughout the research, we did observe that individuals explained their MWL in various ways at different research stages. Before using the device, they imagine MWL as cognitive ability or emotion issues. While they record WL in their ways, they define it as stress or work quantity. After and during using the tracking device, they consider it as stress or attention.

✗ ***It also doesn't matter what level of metric abstraction is provided.***

As there are multiple interpretations, it results in users' confusion about those terms and metrics. Not to mention, stress can occur at any time and is highly subjective in nature. It remains a question that can we find a general standard to define different levels of MWL. Unlike blood pressure or heart rate, there are no universally clear definitions of good or bad MWL. I believe that for users, this lack of standardized cognitive data may be the biggest issue. It makes it challenging for them to understand the importance of quantifying and tracking cognitive data. Consequently, perhaps the absence of reliable standards leads to distrust and skepticism.

So, after quantified, how do we convince users the accuracy of cognitive data?

How do people value the accuracy of cognitive data?

Throughout the research, various methods were attempted to address the issue of distrust and skepticism through literature review and user testing. Yang et al. (2015, September) emphasized the importance of presenting the correct data trend as sufficient, while Gulotta et al. (2016, June) advocated for the significance of enabling users to do small tests and calibration.

The results from the user tests align with Yang et al. (2015, September)'s argument and contradict Gulotta et al. (2016, June)'s advocacy.

✗ ***Calibration is deemed unhelpful by users, as they consider themselves non-experts in cognition and are hesitant to influence the results.***

✓ ***Demonstrating the correct trend of data changes is sufficient for them to confirm that the device is effectively monitoring their brain activity.***

Regarding calibration, it is also influenced by how frequently people access the data. According to the results of the user test, individuals don't regularly check the data, let alone calibrate it multiple times to establish a comprehensive database. Additionally, to maintain focus, most people don't access the data while working. Therefore, this also raises the issue of how to provide users with a good user experience within limited and discontinuous time frames.

On the other hand, if the data trend helps users confirm the accuracy of the data, in other words, this is something users believe they already know. Going back to the exploratory interviews, many participants indeed suggested that they believe they don't need data to understand their own state. Therefore, can we say that, typically, people have a general idea of their state, but it's the details they want to explore? For instance, the magnitude of changes, reasons for changes, frequency of changes, and so on. Perhaps these information will stimulate more reflections for users.

However, do users really reflect on cognitive data?

According to Li et al. (2010), in the model of self-tracking Personal Informatics (PI), it is crucial to consider the reflection stage as it guides the subsequent self-tracking. However, it is not necessary to take action after reflection.

Referring back to related literature reviews, Midha et al. (2022) outlined three positive impacts of measuring MWL: recognizing the varying implications of different levels of MWL, being aware of preventing sustained mental workload at the same level, and being able to confirm whether one has entered the ideal state. However, these three aspects actually have minimal significance for users.

Firstly, it has been observed that individuals only concern themselves with MWL when in bad situations.

They are not interested in tracking their MWL outside of working hours and are indifferent to their performance during periods of low MWL. Furthermore, they consider tracking MWL to be a stressful behavior as it implies a need for improvement based on the data collected.

Secondly, work requirements often prevent individuals from transitioning between states.

Providing such information may seem overly idealistic. Considering that if I've finally managed to enter a state of concentration, why should I change it? Such functions have been proven to be intrusive for users.

Finally, users are not convinced of the concept of an "ideal state."

As discussed earlier, everyone perceives mental workload differently, and each person has different goal states. During the user tests, some participants questioned who defined these ideal states and how to ensure that these standards align with their own goals. It seems that providing too many definitions or boundaries regarding cognitive performance may make users feel more uncomfortable or skeptical.

Then, what can we reflect on MWL data indeed?

From the exploratory phase, this study has been exploring what reflections we can derive from tracking MWL. However, whether through interviews or user tests, we have struggled to find the key point to reflect. It is obvious that understanding the current cognitive data may not lead to any change or reflection for the users, and I believe this may be because we do not know how to change our cognitive states.

As one interviewee put it, "My cognitive state is not something I can change just because I want to change it. I also have no idea how to adjust my values to an ideal value." When we prompt users to reflect on something that is difficult to tangibly improve, they may not know what reflection and actions to take.

Therefore, I believe we need to shift the focus of reflection from uncontrollable cognitive states to controllable work outcomes. Factors such as workload and work duration are examples of variables that may influence MWL results and are within our control. Visible improvements in work outcomes can effectively prompt individuals to reflect on their cognitive resource allocation.

Just as people may not fully understand themselves because they cannot see their own behavior from their own perspective, they may actually not understand themselves better than others do. Our understanding of our own cognitive state is also ambiguous and requires examination through different media or from different perspectives.

Furthermore, in line with Gulotta et al. (2016, June)'s proposition that personalized features can effectively stimulate reflection and periodic introspection, the research also found that when it comes to cognitive data and performance, it is more crucial to compare oneself rather than comparing with standards defined by others.

However, how to compare with ourselves is something only that person knows, including which indicators that person wants to compare, such as time consumption or task complexity. Therefore, allowing personalized functions is essential when demonstrating cognitive data.

Reference

- Annett, J. (2002). Subjective rating scales: science or art?. Ergonomics, 45(14), 966-987.
- Bagheri, M., & Power, S. D. (2020). EEG-based detection of mental workload level and stress: The effect of variation in each state on classification of the other. Journal of Neural Engineering, 17(5), 056015.
- Blom, J. O., & Monk, A. F. (2003). Theory of personalization of appearance: Why users personalize their PCs and mobile phones. Human-computer interaction, 18(3), 193-228.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101.
- British Standards Institution (BSI). (1994). Accuracy (trueness and precision) of measurement methods and results—Part 1: General principles and definitions.
- Cain, B. (2007). A review of the mental workload literature. DTIC Document.
- Casali, J. G., & Wierwille, W. W. (1984). On the measurement of pilot perceptual workload: a comparison of assessment techniques addressing sensitivity and intrusion issues. Ergonomics, 27(10), 1033-1050.
- Chatzitsakyris, P., Ducla-Soares, G., & Zulas, A. (2004, April). IN-Visible: Perceiving invisible urban information through ambient media. In CHI'04 Extended Abstracts on Human Factors in Computing Systems (pp. 1348-1350).
- Daly, J., Kellehear, A., & Gliksman, M. (1997). The public health researcher: A methodological approach. Melbourne, Australia: Oxford University Press.
- Epstein, D. A., Ping, A., Fogarty, J., & Munson, S. A. (2015, September). A lived informatics model of personal informatics. In Proceedings of the 2015 ACM international joint conference on pervasive and ubiquitous computing (pp. 731-742).
- Estes, S. (2015). The workload curve: Subjective mental workload. Human factors, 57(7), 1174-1187.
- Fokkinga, S. F., & Desmet, P. M. A. (2022). Emotion Typology.
- Gagnon, J. F., Durantin, G., Vachon, F., Causse, M., Tremblay, S., & Dehais, F. (2012). Anticipating human error before it happens: towards a psychophysiological model for online prediction of mental workload.
- Gaillard, A. (1993). Comparing the concepts of mental load and stress. Ergonomics, 36(9), 991–1005. 10.1080/00140139308967972
- Gopher, D. and Donchin, E. (1986). Workload – An examination of the concept. Handbook of Perception andHuman Performance. Volume 2. Cognitive Processes and Performance. K.R. Boff, L. Kaufman andJ.P. Thomas, John Wiley and Sons, Inc: 41-1:41-49.
- Gulotta, R., Forlizzi, J., Yang, R., & Newman, M. W. (2016, June). Fostering engagement with personal informatics systems. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (pp. 286-300).
- Hancock, P. A., & Meshkati, N. (Eds.). (1988). Human mental workload (Vol. 52). Amsterdam: North-Holland.
- Hart, S.G. and Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical andtheoretical research. Human Mental Workload. P.A.M. Hancock, N. Amsterdam, North-Holland: 139-183.
- Hidalgo-Muñoz, A. R., Mouratille, D., Matton, N., Causse, M., Rouillard, Y., & El-Yagoubi, R. (2018). Cardiovascular correlates of emotional state, cognitive workload and time-on-task effect during a realistic flight simulation. International Journal of Psychophysiology, 128, 62-69.
- Jex, H.R. (1988). Measuring mental workload: Problems, progress, and promises. Human Mental Workload.P.A. Hancock and N. Meshkati. Amsterdam, NL, Elsevier Science Publishers B.V. (North-Holland): 5-39.
- Lazarus, R. S., & Folkman, S. (1984). Stress, appraisal, and coping. Springer publishing company.
- Li, I., Dey, A., & Forlizzi, J. (2010, April). A stage-based model of personal informatics systems. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 557-566).
- Lysaght, R.J., Hill, S.G., et al. (1989). Operator workload: comprehensive review and evaluation of operatorworkload methodologies. Fort Bliss, Texas, U.S. Army Research Institute for the Behavioural and SocialSciences: 262.
- Mackinlay, M. Z. (2013). Phases of accuracy diagnosis:(in) visibility of system status in the Fitbit. Intersect: The Stanford Journal of Science, Technology, and Society, 6(2).
- Marit Bentvelzen, Jasmin Niess, and Pawel W Wozniak. Designing reflective derived metrics for fitness trackers. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 6(4):1–19, 2023
- Midha, S., Wilson, M. L., & Sharples, S. (2022, April). Lived Experiences of Mental Workload in Everyday Life. In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (pp. 1-16).
- Mihevic, P. M. (1981). Sensory cues for perceived exertion: a review. Medicine and science in sports and exercise, 13(3), 150-163.
- Ranchet, M., Morgan, J. C., Akinwuntan, A. E., & Devos, H. (2017). Cognitive workload across the spectrum of cognitive impairments: A systematic review of physiological measures. Neuroscience & Biobehavioral Reviews, 80, 516-537.
- Rapp, A., & Tirassa, M. (2017). Know thyself: a theory of the self for personal informatics. Human–Computer Interaction, 32(5-6), 335-380.
- Reid, G.B. and Nygren, T.E. (1988). The subjective workload assessment technique: A scaling procedure formeasuring mental workload. Human Mental Workload. P.A.M. Hancock, N. Amsterdam, Elsevier SciencePublishers B.V. (North-Holland): 185-218.
- Rubio, S., Díaz, E., Martín, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. Applied psychology, 53(1), 61-86.
- Russell, J. A. (1980). A circumplex model of affect. Journal of personality and social psychology, 39(6), 1161.
- Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. Co-design, 4(1), 5-18.
- Schwanda, V., Ibara, S., Reynolds, L., & Cosley, D. (2011, May). Side effects and" gateway" tools: advocating a broader look at evaluating persuasive systems. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 345-348).
- Shashidhar, R., Tippannavar, S. S., Sushma, B. S., & Shukla, P. (2023, February). Smart Electric Wheelchair for disabled and paralyzed person using Attention Values on Arduino. In 2023 International Conference on Recent Trends in Electronics and Communication (ICRTEC) (pp. 1-5). IEEE.ISO 690
- Stasko, J. (2014, November). Value-driven evaluation of visualizations. In Proceedings of the Fifth Workshop on Beyond Time and Errors: Novel Evaluation Methods for Visualization (pp. 46-53).
- Wilson, G. F. (2002). An analysis of mental workload in pilots during flight using multiple psychophysiological measures. The International Journal of Aviation Psychology, 12(1), 3-18.
- Yang, R., Shin, E., Newman, M. W., & Ackerman, M. S. (2015, September). When fitness trackers don't'fit' end-user difficulties in the assessment of personal tracking device accuracy. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (pp. 623-634).
- Young, M. S., Brookhuis, K. A., Wickens, C. D., & Hancock, P. A. (2015). State of science: mental workload in ergonomics. Ergonomics, 58(1), 1-17.

Appendix

Appendix A- Thematic analysis process
(generated themes in Chapter Two)

Appendix B-Tools of card sorting
(Used in Chapter Four)

Appendix C-Results of card sorting
(Used in Chapter Four)

Appendix D-Responses of Survey
(Chapter Five)

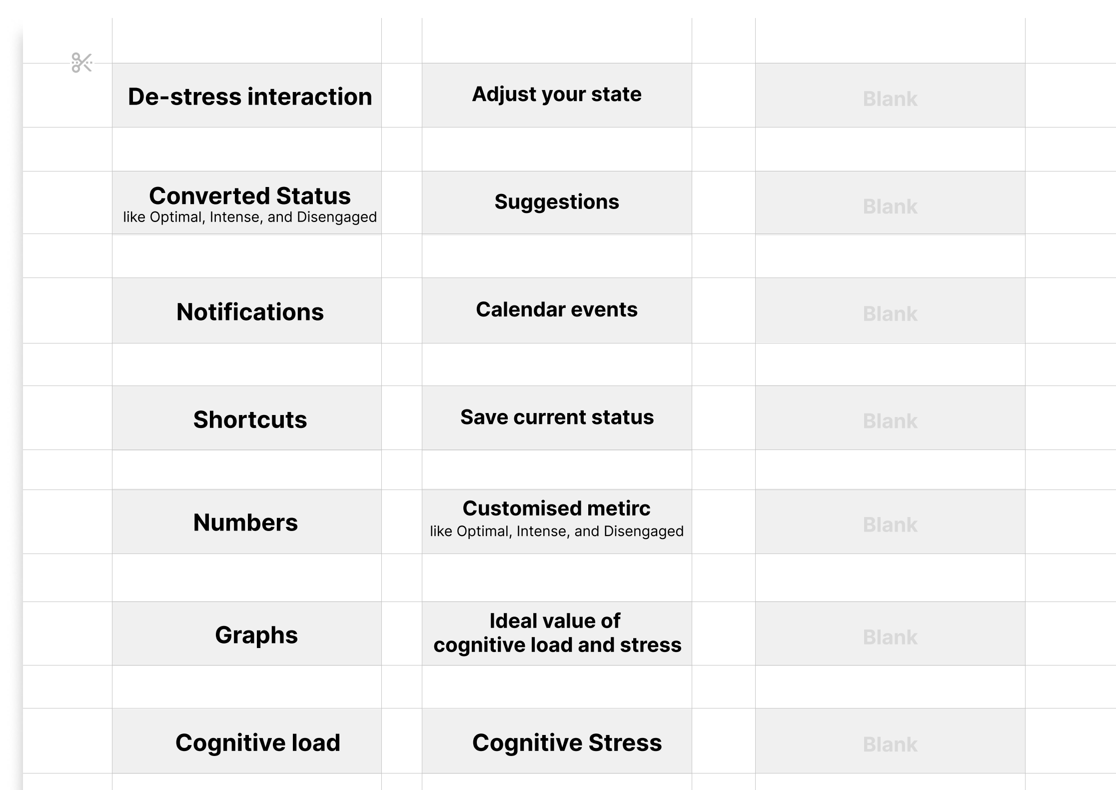
Appendix E-Graduation Brief

Appendix A- Thematic analysis process (generated themes in Chapter Two)

Different levels of data within a tracker	information	tracker function: verify						
	data	tracker function: behavior record	tracker funtion: quality	tracker function: reminder				
	knowledge	tracker function: adjustment						
Long-term and short-term impact of motivation	first-time user	first experience						
	experience	Personal affection	Tracking Motivation: A Sense of Achievement	Tracking motivation: curiosity and novelty				
	goals	Tracking motivation: verify	self exploring	needs to understand the causes of negative status, stress	Tracking Motivation: Efficiency and Focus	health decline	tracking motivation: uncontrollable	
Incorrect information at incorrect timing	after	reflecting timing: feeling negative	reflecting timing: afterwards					
	during	tracking time: task duration						
	current	Doubt of using timing: distracting	Doubt of using timing: not helpful	Doubt of using timing: more stressed				
Indifferent and distrust	passive and don't want to change anything	Passive Product Selection	Passive attitude of knowing current condition	need not to change current status	emotion health awareness			
	offensive	Attitude of tracking: invading privacy						
	suspicious	Curiosity of physiological (scientific) reaction						
	uncertain	Uncertainty of how to react to data						
	Ambiguity of metric itself (one)	Ambiguity of the metric	uncertainty of the measurement and definition of a metric					
	uncertain about differences between two	Uncertainty about the relationship between interest and excitement	Uncertainty about the relationship between stress and focus					
	doubt	Doubt that data cannot change the fact						
	confident	Unimportant Status: relaxed	Information that was already known					
	match actual situation	data (do not) matches the actual situation						
	potential of "prediction"	accuracy contribute to prediction						
	distinguish different state	Doubts about the accuracy of the data to distinguish the state						
	measurement	Views on the Accuracy of Mental State Measurements						
Different ways to help different users	notice	needs: remind of unconscious problem						
	idea state	suggestions for target status	check if enter target state					
	learn new things	needs: data information's impact	Needs: prediction	suggestion of dealing with reults	Curiosity of physiological (scientific) reaction	needs to understand the causes of negative status, stress	Increasing interpretability: emotions	Increasing interpretability: Reasoning
	destress	needs of stabilising stress	Interest of solving emotional problem					
Work-centric self-tracking	work-related	interest exhaustion and active level	right state "concentrated"	interet of stress	interest of focus	active status: engaging, effciency	Value negative results from prolonged stress: Exhaustion	
	classification	seperate "peak" and "lowest points" and "not idea state"	typical day and day-off	Unnecessary tracking: daily things	Recall: out of original plan	fixed recall theme		
	focus	focus on peak points	focus on the average	focus on big fluctuation	recall theme	High MWL Recall	Recall: meaningful and connected	Recall: dynamic emotion change
	panic	Questioned Data: Sense of Panic						

Biased understanding on MWL	stand stress	assotiating MWL with accumulated stress	associating MWL with limited stress	assotiating mental load with stress	associating high MWL with "pressure"					
	stand emotion	Associating bad MWL to negative emotions or lack of concentration	defining MWL as psychological limitation	defining MWL as the willingness to deal with things	Description of MWL: using adjectives	associating high MWL with "uncontrollable"	associating high MWL with "emotional issues"	Future concerns	associating high MWL with fully attention	associating high MWL with "intense"
	stand cognition	defining MWL as brain efficacy	differentiate high and low MWL: more or less thinking	separating cognition and mental worklaod : internal and external information						
Limited explanatory space	mental = familar , eomtional but vague	More familiar with mental state	assotiating mental load with emotion	tangible mental feeling and abstract cognition						
	cognition = concrete and obvious	more aware of cognitive state	sense with know more of "cognition workload"							
	cognition,thinking	assotiating cognition load with understanding the world	Defining cognition workload through how much effort needed for a task	assotiating cognitive load with "rational"	assotiating cognitive load with physically doing things	assotiating cognitive load with physically doing things	Low MWL refers to less thinking	Low MWL refers to " not difficult"		
The confused classifications of MWL from user perspective	low MWL	hard to specify low MWL	Uncertainty about the definition of low MWL and doing nothing							
	definition of good	defining good MWL : a bit challenging	defining good MWL : adequate values and duration							
	Preconceived Impressions-activities	expaining MWL through activites - high: reading	expaining MWL through activites- low:doing laundry	separating high and low MWL through achieving the goal of that day						

Appendix B-Tools of card sorting (Used in Chapter Four)



Appendix C -Results of card sorting (Used in Chapter Four)

Card sorting : E1

Must have	Nice to have	Unnecessary
Numbers	Shortcuts	Calendar events
Graphs	De-stress interaction	Customised metric like Optimal, Intense, and Disengaged
Cognitive load	Suggestions	
Cognitive Stress	Notifications	
Ideal value of cognitive load and stress		
Converted Status like Optimal, Intense, and Disengaged		
Save current status		

Card sorting : E2

Must have	Nice to have	Unnecessary
Numbers	De-stress interaction	Shortcuts
Graphs	Suggestions	
Cognitive load	Calendar events	
Cognitive Stress	Ideal value of cognitive load and stress	
Notifications		
Converted Status like Optimal, Intense, and Disengaged		
Customised metric like Optimal, Intense, and Disengaged		
Save current status		

Card sorting : E3

Must have	Nice to have	Unnecessary
Numbers	Notifications	Save current status
Graphs	Cognitive load	Shortcuts
Converted Status like Optimal, Intense, and Disengaged	Cognitive Stress	De-stress interaction
Suggestions	Customised metric like Optimal, Intense, and Disengaged	
Calendar events	Ideal value of cognitive load and stress	
Data Summary*		

Card sorting : E4

Must have	Nice to have	Unnecessary
Numbers	Shortcuts	Converted Status like Optimal, Intense, and Disengaged
Graphs	De-stress interaction	Customised metric like Optimal, Intense, and Disengaged
Cognitive load	Notifications	Suggestions
Cognitive Stress		Ideal value of cognitive load and stress
Calendar events		
Save current status		

Card sorting : E5

Must have	Nice to have	Unnecessary
Calendar events	De-stress interaction	Shortcuts
Graphs	Notifications	Ideal value of cognitive load and stress
Save current status	Cognitive load	Numbers
Suggestions	Cognitive Stress	
	Customised metric like Optimal, Intense, and Disengaged	
	Explanation of metrics*	
	Converted Status like Optimal, Intense, and Disengaged	

Card sorting : E6

Must have	Nice to have	Unnecessary
Numbers	Shortcuts	Converted Status like Optimal, Intense, and Disengaged
Graphs	De-stress interaction	Customised metric like Optimal, Intense, and Disengaged
Cognitive load	Suggestions	Notifications
Cognitive Stress	Calendar events	
Ideal value of cognitive load and stress		
Save current status		

Card sorting : E7

Must have	Nice to have	Unnecessary
Numbers	Notifications	Customised metric like Optimal, Intense, and Disengaged
Graphs	Suggestions	De-stress interaction
Cognitive load	Save current status	
Cognitive Stress		
Shortcuts		
Converted Status like Optimal, Intense, and Disengaged		
Ideal value of cognitive load and stress		
Calendar events		

Card sorting : E8

Must have	Nice to have	Unnecessary
Numbers	Suggestions	Notifications
Graphs	Ideal value of cognitive load and stress	Save current status
Cognitive load	Customised metric like Optimal, Intense, and Disengaged	De-stress interaction
Cognitive Stress	Converted Status like Optimal, Intense, and Disengaged	Shortcuts
Work time recording*	Calendar events	

Card sorting : E9

Must have	Nice to have	Unnecessary
Numbers	Shortcuts	Ideal value of cognitive load and stress
Graphs	De-stress interaction	
Cognitive load	Suggestions	
Cognitive Stress	Notifications	
Calendar events	Customised metric like Optimal, Intense, and Disengaged	
	Converted Status like Optimal, Intense, and Disengaged	
	Save current status	

Card sorting : E10

Must have	Nice to have	Unnecessary
Numbers	Customised metric like Optimal, Intense, and Disengaged	Shortcuts
Graphs	De-stress interaction	Save current status
Cognitive load	Suggestions	
Cognitive Stress		
Converted Status like Optimal, Intense, and Disengaged		
Ideal value of cognitive load and stress		
Notifications		
Calendar events		

Appendix D -Responses of Survey (Chapter Five)

	Words used to describe workload		Words used to describe stress		Rating of workload and stress overlap
	Negative	Positive	Negative	No positive words	Rate / 5
B1	*15% Doubt* *10% nervousness* *30% Worry*	*10% Inspiration* *20% Satisfaction* *15% Moved*	*50% Anxiety* *10% Fear* *15% Worry* *25% Distress*		*4*
B2	*45% Anxiety* *45% Self-hatred* *10% self-abandoned*		*45% Anxiety* *45% Self-hatred* *10% self-abandoned*		*5*
B3	*30% Anxiety* *10% Boredom* *20% Frustration*	*20% Satisfaction & achievement* *10% Excitement* *10% Pride*	*25% Fear* *25% Anxiety* *25% Insecurity* *25% loneliness*		*3*
B4	*45% Anxiety* *20% Frustration* *5% Dissatisfaction*	*25% Gratitude* *3% Inspiration* *2% Others*	*50% Anxiety* *15% Nervous* *15% Frustration* *15% Dissatisfaction* *15% Doubt*		*4*
B5	*40% Anxiety* *5% Frustration* *5% Worry* *5% Annoyance*	*30% DETERMINATION* *15% Positive surprise*	*40% Anxiety* *20% Embarrassment* *10% Regret* *10% Fear* *10% Shame*		*2*
B6	*30% Anxiety* *30% Guit*	*40% Excitement*	*50% Guilt* *25% Fear* *25% Worry*		*3*
B7	*30% Reluctance & boredom*	*40% serenity* *30% excitement, happy-for, satisfaction, positive surprise, Inspiration, hope, determination*	*20% Confusion* *10% Nervousness* *70% Anxiety*		*5*
B8	*40% Anxiety* *5% annoyance* *20% dissatisfaction* *30% Frustration + disappointment*	*1% DETERMINATION* *2% pride+satisfation*	*70% Anxiety* *20% Frustration* *10% dissatisfaction + disappointment*		*4*
B9	*5% Frustration* *5% Guilty* *25% Anxiety* *25% dissatisfaction*	*5% Pride* *25% Satisfaction*	*50% Anxiety 10% Satisfaction* *10% Worry* *10% Nervous* *20% Annoyance*		*3*
B10	*20% Worry*	*50% Excitement* *30% Hope*	*50% Boredom* *50% Anxiety*		*2*

Appendix E-Graduation Brief

TUDelft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:
- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Chen	IDE master(s)	IPD ☐ DfI ✔ SPD ☐
Initials	Y.W	2nd non-IDE master	
Given name	Yuwei	Individual programme *(date of approval)*	
Student number	5021391	Medisign	✔
		HPM	☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Dr. Schneegass, C.	dept./section	HCD. / HICD.
mentor	Dr. Dingler, T.	dept./section	SDE. /HCAI.
2nd mentor			
client:			
city:		country:	
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Christina Schneegass — Digitally signed by Christina Schneegass Date: 2023.10.09 14:46:36 +02'00'

Name Christina Schneegass Date 04.10.2023 Signature

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

★	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Robin den Braber — Digitaal ondertekend door Robin den Braber Datum: 2023.10.11 07:45:46 +02'00'

Name Robin den Braber Date 11-10-2023 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:
31/10/2023 Arjen Jansen sent an email to the chair with remarks about the Medisign spec.

Sign for approval (BoEx)

Monique von Morgen — Digitally signed by Monique von Morgen Date: 2023.10.31 11:03:09 +01'00'

Name Monique von Morgen Date 31/10/2023 Signature

Appendix E-Graduation Brief

TU Delft

DESIGN FOR our future

Personal Project Brief – IDE Master Graduation Project

Name student Yuwei Chen **Student number** 5021391

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Designing meaningful interaction with mental workload data

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Context
Excessive psychological stress has been confirmed as a significant factor in workplace errors and safety hazards. Tracking individuals' Mental Workload through wearable technology is under development and will be accomplished in the not-too-distant future.Therefore, by interpreting an individual's EEG data or other physiological data, it is possible to assess one's Mental Workload. However, despite existing research, there is a lack of understanding from a user perspective regarding how to interpret and utilize such data. Furthermore, there is a dearth of research on how to present these data to users to enhance or improve their experience.

Opportunities
Research has indicated that different levels of Mental Workload (MWL) can lead to varying experiences or outcomes, and it has explored the positive and negative effects that are probably associated with the sustain and transitions of different MWL levels. However, how to interpret these different levels into wordings that can be easily understood by users and reflective remains a challenge. For instance, users usually express they are "stressed" or "relaxed". How can we make these quantitive data closer to our daily life?

Stakeholder
Individuals who are used to tracking their physiological data / personal informatics through wearable devices, Relatives, existing product brands (like Nerosity and Qura Ring. etc.), and healthcare professionals who may use MWL data to provide health recommendations

Limitations
Due to the current technical limitations in the way of measurement and accuracy of interpreting EEG data, as well as how to wear the device all the time, this study will primarily focus on assisting users in understanding and

➔ *space available for images / figures on next page*

introduction (continued): space for images

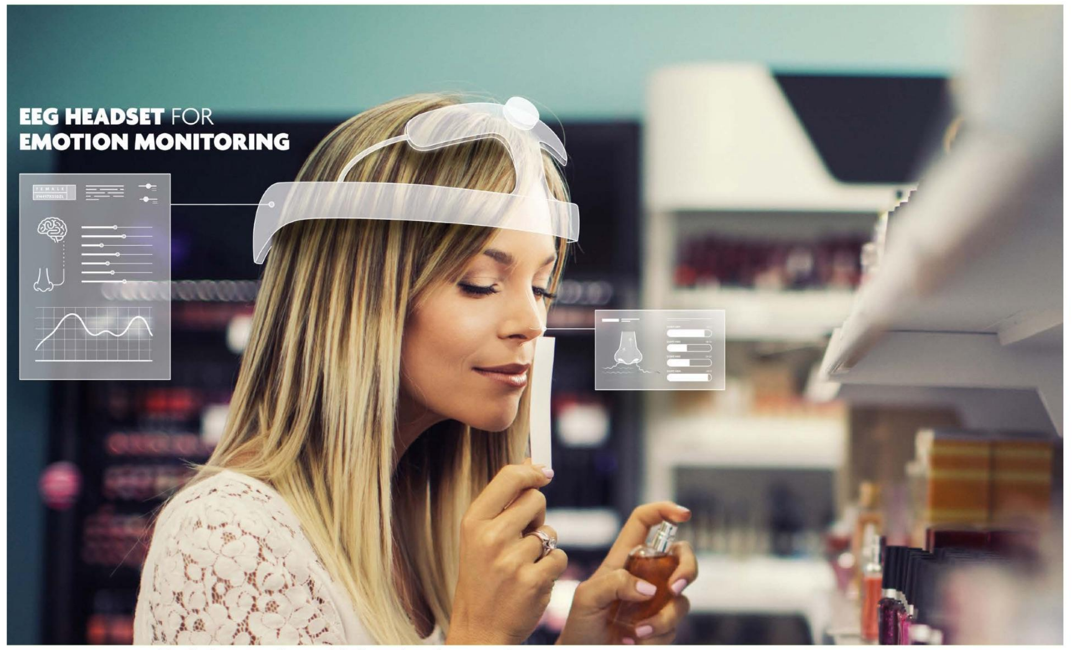


image / figure 1 Exsisting product with imagined scenario

image / figure 2 Example of expected design outcome

Appendix E-Graduation Brief

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

RQ1. Investigating individuals' understanding and expectation of Mental Workload (MWL)

RQ2. Exploring the distinctions between different MWL levels and common mental expressions (i.g. Stress, Depression)

RQ3. Exploring different meanings and goals of using MWL data in different using timing (Before, during, after use)

RQ4. Transforming MWL into reflective metrics and visuals

RQ5. (optional)Developing design guideline of presenting MWL data on wearable devices

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Investigate and design a guideline to help users understand and utilize their real-time mental workload data

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

1. This research will mainly focus on how users can utilize MWL data. As a result, it's essential to understand how users understand these data, how to connect these data to our daily lives, and what is the overall use process. For these research questions, I will conduct literature review and desk research to understand the design of existing products and recent research.

2. Thereafter, due to technical limitations, this would be more like speculative research. Therefore, I plan to make some prototypes to understand users' opinions. The methodology of user research is not fixed at this moment.

3. In the end, the design outcome is expected in the form of interface design or design guidelines and will be validated if necessary.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	4 10 2023
Mid-term evaluation	16 11 2023
Green light meeting	25 1 2024
Graduation ceremony	22 2 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

Expanding my knowledge in a new field
As a DFI (Design for Interaction) student, I would prefer to find a topic related to user research and interaction design space. Additionally, I have a strong interest in medical design and psychology. This topic aligns well with my expectations for my graduation project. It offers an opportunity to expand my knowledge in a new field, and it's also exciting because the measurement of Mental Workload technology is already in development but still requires user research and design input. I am enthusiastic about contributing to this emerging topic in any way I can.

Applying research in design
During my previous projects, I usually realized there was a gap between research and design. We used to work on mature products and lose the direction of understanding users and products. This would be a nice opportunity for me to start from focusing on research and turn insights into design, and I hope by the end of this project, my research will be closely associated with the design.

Analyzing quantitative and qualitative data in a structured manner
I hope no matter what kind of user research I will do in the end, the final analysis results will be conducted in a structured manner. In particular, I would like to learn how to analyze qualitative data, such as qualitative coding.