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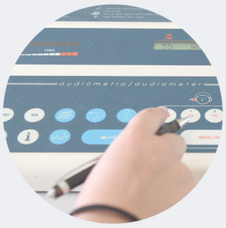

Unveiling the Psyche: A Scientific Safari into Occupational Determinants of Cognitive Function and Psychological Well-being through Pupillometry

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P.PORTO

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Unveiling the Psyche: A Scientific Safari into Occupational Determinants of Cognitive Function and Psychological Well-being through Pupillometry

Validation of Pupillometry Equipment and Assessment of Occupational Determinants of Cognitive Function and Psychological Well-being

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Dissertação para obtenção do Grau de Mestre em Engenharia Biomédica

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Resumo

Esta dissertação, em primeiro lugar, tem como objetivo realizar uma pré-validação do equipamento de rastreamento ocular Pupil Labs Core (PLC). Pretende-se verificar assim a fiabilidade do equipamento, para que posteriormente, este seja usado para avaliar determinantes da função cognitiva e do bem-estar psicológico (FCBP), sendo este o segundo objetivo do estudo. Aqui comparou-se os resultados da pupilometria com medidas subjetivas, em duas condições de iluminância diferentes. De forma a entender os objetivos foram descritos conceitos fundamentais, com os seguintes pontos-chave. A pupilometria revela determinantes da FCBP, refletindo os estados emocionais e cognitivos dos trabalhadores. A dilatação da pupila correlaciona-se com o aumento da carga de trabalho, stresse e atenção, enquanto a constrição está associada à fadiga e sonolência. Os riscos psicossociais no local de trabalho afetam significativamente a saúde mental e física dos trabalhadores, o desempenho, a satisfação e os custos organizacionais. A tecnologia de rastreamento ocular tem amplas aplicações na psicologia ocupacional, revelando processos cognitivos e emoções em ambientes reais. Ainda em termos teóricos, foi realizada, a comparação de medidas subjetivas e objetivas para os determinantes da FCBP em estudo, na qual se obteve os pontos chave a seguir descritos. A captura imediata de dados ao observar as reações dos utilizadores é mais eficaz do que a análise pós-tarefa. Diversas ferramentas subjetivas avaliam o stresse e a fadiga para risco psicológico, mas carecem de direcionamento específico para as tarefas, tornando preferenciais as medidas objetivas. As medidas objetivas são favorecidas para avaliações de atenção. Nas medições subjetivas, a *Visual Analogue Scale* (VAS) é adequada para o stresse, a fadiga e a atenção relacionados à tarefa. As métricas de rastreamento ocular e a medição de desempenho são consideradas os métodos objetivos mais confiáveis para avaliar carga de trabalho, fadiga, stress e atenção em conjunto. De seguida, apresentou-se a metodologia, os resultados, a discussão e a conclusão referente à validação dos PLC. Nesta fase, os valores do diâmetro da pupila dos óculos PLC foram comparados com os valores de um equipamento médico validado e amplamente utilizado. Os resultados mostraram uma elevada correlação entre os valores obtidos validando o equipamento PLC. No entanto, uma validação com níveis de iluminância superiores é recomendada. Por último, apresentou-se a metodologia, resultados, discussão e conclusão referentes à avaliação dos determinantes da FCBP. Aqui, os resultados vão de encontro à literatura quando comparando os valores do diâmetro da pupila com o aumento ou diminuição da carga de trabalho, stresse, atenção e fadiga. Além disto, os métodos objetivos apresentaram resultados mais fidedignos em comparação aos subjetivos, pela diferença da interpretação dos participantes nestes últimos. Adicionalmente, os resultados mostraram que um ambiente de 500 lux conduz a níveis reduzidos nos determinantes da FCBP, sendo este o ambiente ideal a aplicar nos locais de trabalho para aumentar a saúde mental e a eficiência dos trabalhadores.

Palavras-chave: Óculos *Pupil Labs Core*; Tamanho da pupila; Carga de trabalho; Stresse; Fadiga; Atenção

Abstract

The first primary objective of the study was to conduct a pre-test validation of the Pupil Labs Core (PLC) eye-tracking glasses. The second aim was to assess the accuracy of PLC glasses in measuring changes in pupil diameter to evaluate determinants of cognitive function and psychological well-being (CFPW), comparing results with subjective methods. To better understand the aims of the study, fundamental concepts were explained, including eye anatomy, determinants of CFPW, their effects, and eye-tracking. Additionally, a review of current subjective and objective approaches for assessing determinants of CFPW was included. Next, the methodology and findings of PLC validation were described, revealing strong correlations between PLC and the gold standard equipment, validating PLC. However further validation under higher illuminance lighting conditions is recommended. Following, the methodology and outcomes of the determinants of CFPW assessment was presented, indicating consistent results with literature regarding pupil size and workload, fatigue, stress, and attention. Objective methods proved superior in analysing these factors compared to subjective scales due to participant bias in interpretating the latter. Notably, participants identified 500 lux as the optimal lighting condition objectively and subjectively, suggesting workplaces should adopt this light level to enhance productivity and mental health.

Keywords: Pupil Labs Core glasses; Pupil size; Workload; Stress; Fatigue; Attention

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Acronyms and Symbols

Acronyms List

ADHD	Attention Deficit Hyperactivity Disorder
AHP	Analytical Hierarchy Process
ANS	Autonomic Nervous System
AOI	Area(s) of interest
ARDs	Attention-Related Disorders
BMI	Body Max Index
BP	Blood pressure
BVP	Blood Volume Pulse
CAD	Coronary Artery Disease
cd	Candela
CF	Chadler Fatigue Scale
CFS	Chronic Fatigue Syndrome
CFPW	Cognitive Functions and Psychological Well-being
CIS	Checklist Individual Strength
CNNs	Convolutional Neural Networks
COPE	Coping Orientation to Problems Experienced
CR	Corneal Reflection
CVD	Cardiovascular diseases
DALYs	Disability-Adjusted Life Years
DASS	Depression Anxiety and Stress Scale
dB	Decibels
EASHW	European Agency for Safety and Health at Work
ECG	Electrocardiogram

EDA	Electrodermal Activity
EEG	Electroencephalography
EMG	Electromyogram
EOG	Electrooculogram
EU	European Union
FAS	Fatigue Assessment Scale
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-infrared spectroscopy
FSS	Fatigue Severity Scale
GSR	Galvanic Skin Response
HCI	Human-Computer Interaction
HPA	Hypothalamus-pituitary-adrenal
HR	Heart Rate
HRV	Heart Rate Variability
ILO	International Labor Organization
ipRCGs	Intrinsically Photosensitive Retinal Ganglion Cells
ISA	Instantaneous Self-Assessment
ISO	International Standard Organization
IWS	Integrated Workload Scale
JDC	Job Demand-Control
lm	Lumen
LSSI	Lipp's stress symptoms inventory
MBI	Maslach Burnout Inventory
MCH	Modified Cooper-Harper
ME	Myalgic Encephalomyelitis
MEG	Magnetoencephalography

MFI	Multidimensional Fatigue Inventory
MRQ	Multiple Resources Questionnaire
NASA-RTLX	National Aeronautics and Space Administration-Raw Task Load Index
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
NRS	Need for Recovery Scale
OFER	Occupational Fatigue Exhaustion Recovery scale
OSH	Occupational Safety and Health
OWS	Overall Workload Scale
p-CR	Pupil minus Corneal Reflection
PET	Positron Emission Tomography
PLC	Pupil Labs Core
PLR	Pupil Light Reflex
PNS	Parasympathetic Nervous System
PO	PlusOptix
POG	Photo-OculoGraphy
POS	Perceived Occupational Stress
PSG	Polysomnography
PSS	Perceived Stress Scale
PSWQ	Penn State Worry Questionnaire
RSME	Rating Scale Mental Effort
RSS	Relative Stress Scale
SCR	Skin Conductance Responses
SNS	Sympathetic Nervous System
SOFI	Swedish Occupational Fatigue Inventory
ST	Skin Temperature
SWAT	Subjective Workload Assessment Technique

SWORD	Subjective Workload Dominance
UX	User experience
VAS	Visual Analogue Scale
VOG	Video-OculoGraphy
VR	Virtual Reality
WCI/TE	Workload/Compensation/Interference/ Technical Effectiveness
WRMSD	Work-related musculoskeletal disorders

1 Introduction

This chapter provides the foundation for the dissertation, contextualizing the study and outlining its objectives and structure.

First, the chapter establishes the context of the study, providing background information and explaining the significance of the research topic. Second, the chapter presents the objectives of the study, which are the specific goals that the research aims to achieve. Finally, the chapter outlines the structure of the dissertation, which is a roadmap for the research.

Overall, this chapter provides a solid foundation for the dissertation, establishing the context, objectives, and structure of the research.

1.1 Contextualization

The International Labor Organization (ILO) has alarming statistics indicating the global toll of work-related accidents and diseases, emphasizing the urgent need for enhanced occupational safety measures. According to the ILO assessment, a staggering 2.3 million individuals, encompassing both men and women, fall victim to work-related incidents every year, resulting in over 6,000 fatalities daily. The global significance of this issue is emphasized by an estimated 340 million occupational accidents and 160 million cases of work-related illnesses annually (ILO, 2021).

Delving into the specific context of Portugal in 2021, a total of 4.453.815 days were lost due to occupational injuries, with temporary incapacity for work, categorized by gender: 3.268.470 for males and 1.185.345 for females. A comparative analysis with the data from 2015, which recorded a total of 4,035,356 days lost, reveals an escalating trend (ILO, 2024c). Likewise, the severity of fatal occupational injuries is underscored by a total of 93 cases in 2021, consisting of 89 males and 4 females, marking a decrease compared to 161 cases in 2015 (ILO, 2024a). Furthermore, non-fatal occupational injuries in 2021 totalled 120,272, with 86,616 cases involving males and 33,656 involving females, showing a notable improvement from the 134,378 reported in 2015 (ILO, 2024b). While these latter two statistics indicate progress, it is crucial to acknowledge that the numbers, though reduced, remain relatively high. These distressing figures underscore the pressing need for a comprehensive and globally coordinated approach to enhance workplace safety and prevent further human losses in the professional sphere.

Recognizing the paramount importance of ensuring workers can perform their duties in conditions prioritizing safety and well-being, occupational safety focuses on preventing work-related accidents by identifying, evaluating, and managing occupational risks. Concurrently, occupational health strives to safeguard and enhance employees' well-being. In Portugal, the overarching guidelines for prevention, along with the broad responsibilities of both employers and workers, are outlined in the current version of the Legal Framework for the Promotion of Safety and Health at Work (Law No. 102/2009, dated September 10) (ACT, 2024).

In the contemporary era, society is experiencing a notable technological shift across various professional domains. The integration of digitalization and automation into workplaces and processes is on the rise, as reported by the European Commission (2021). Concurrently, employees find themselves increasingly immersed in screen-based tasks, with heightened cognitive demands accompanying these changes (European Commission, 2021). However, these advancements bring forth new or exacerbated risks. Notably, mental and cognitive factors, capable of precipitating occupational diseases and accidents, emerge as significant concerns amid these transformations (Kalakoski *et al.*, 2020; Bonsang and Caroli, 2021). The significance of this issue is underscored by its incorporation as one of the key objectives within the EU Strategic Framework on Health and Safety at Work (European Commission, 2021). Consequently, safeguarding the mental and cognitive well-being of workers is imperative, not only for health and safety but also for economic considerations.

Addressing the mental and cognitive aspects of workers may involve employing biometric measures, such as monitoring pupil size. In the realm of occupational safety and health (OSH), the fluctuation in pupil size is indicative of individuals' concentration, focus, relaxation, and overall cognitive processes (Wangwiwattana, Ding and Larson, 2018). Consequently, the measurement of pupil size holds potential applications for monitoring and enhancing OSH practices (Iqbal, Srinivasan and Srinivasan, 2018; Menekse Dalveren *et al.*, 2018) Given the significant influence of mental states and cognitive abilities on individual performance and, by extension, overall system functionality, the utilization of pupil size monitoring emerges as a valuable tool. This approach, as suggested by Dalveren and Cagiltay (2018), offers insights to prevent human errors, bolster safety measures, and elevate productivity. Pupillometry, as a non-invasive metric, can be acquired without disrupting normal behaviour, rendering it a well-explored index in the existing literature (see, for instance, Binda, Pereverzeva and Murray, 2014; Binda and Murray, 2015; Cao et al., 2021). In this context, the choice of pupillometry as a method for evaluating mental workload is particularly advantageous.

Therefore, assessing mental workload in occupational settings holds paramount importance, contributing to employee well-being, safety, and overall productivity. Understanding the cognitive demands placed on workers allows for proactive measures to prevent occupational accidents and errors. Pupillometry, with its sensitivity to changes in cognitive and mental states, can provide real-time insights into the dynamic nature of the workload experienced by individuals. Its non-invasive nature and ability to capture subtle variations make it a versatile tool for assessing mental workload across diverse work environments, establishing it as a preferred and effective means of evaluating mental workload in occupational settings.

1.1.1 Research questions

In contemporary work environments, characterized by increasing demands and pressures, there is a critical need for effective methods to assess and monitor determinants of cognitive function and psychological well-being (CFPW) among employees. Prolonged exposure to factors such as excessive workload, stress, and inadequate lighting conditions can have detrimental effects on employee well-being and performance. To address this challenge, innovative approaches are being explored, including the utilization of advanced technologies such as pupillometry, which has emerged as a promising tool for gauging determinants of CFPW in occupational settings.

The first research question and PICO framework refer to a validation pre-test of the eye tracking Pupil Labs Core glasses used in the methodology.

Are Pupil Labs Core eye tracking glasses capable of measuring pupil size accurately?

Following the PICO framework, for the eye tracking glasses validation:

P: This stage targets people.

I: The study involves measuring pupil size with two different devices.

C: The comparison involves evaluating the effectiveness of pupillometry using eye-tracking glasses against the gold standard equipment

O: The outcome aims to validate for pupillometry the eye tracking glasses in analysis.

The second research question has been phrased as follows:

How effective is pupillometry as an indicator of the determinants of cognitive function and psychological well-being (workload, fatigue, attention, and stress) in workers employed in computer-intensive occupations and real-world industrial applications when compared to other techniques?

Also, the PICO Framework, for the laboratory-controlled environment stage:

P (Population): This stage targets workers employed in computer-intensive occupations, spending a minimum of 3 hours daily in front of a computer screen.

I (Intervention): The study involves the validation of a novel pupillometry methodology utilizing Pupil Labs Core glasses to measure pupil dilation as an indicator of the determinants of CFPW such as workload, fatigue, attention and occupational stress.

C (Comparison): The comparison involves assessing the relationship between determinants of CFPW and pupil dilation. As well as evaluating the reliability and effectiveness of the Pupil Labs Core glasses in measuring the determinants of CFPW compared to subjective methods, such as gold standard questionnaires.

O (Outcome): The study aims to determine the accuracy and viability of the Pupil Labs Core glasses in capturing changes in pupil diameter, thus providing a foundation for subsequent real-world application in industrial settings.

In conclusion, this research endeavours to validate the use of pupillometry, specifically utilizing Pupil Labs Core glasses, as a method for assessing determinants of CFPW. By employing the PICO framework, this study aims to systematically evaluate the effectiveness of this innovative technology in measuring pupil dilation and its potential applications in industrial settings. Ultimately, the findings of this research hold the promise of providing valuable insights into the physiological responses to occupational determinants of CFPW, thereby informing strategies for promoting employee well-being and optimizing workplace environments.

1.2 Objectives

In this research, the primary objectives are twofold, divided into distinct phases, to comprehensively address the evaluation of mental workload using pupillometry.

1.2.1 Part 1: Validation of Pupil Labs Core eye tracking glasses

The initial phase of the study aims to do a validation pre-test of the equipment that will be used in the methodology to assess determinants of CFPW.

- Assess the reliability of the equipment.
- Ensure the equipment’s effectiveness in capturing changes in pupil diameter.

This phase seeks to establish a comparative analysis by cross-referencing the data obtained through the device in validation with a gold standard and used medical device.

1.2.2 Part 2: Laboratory experiment in a simulated working environment

The second phase builds on the validated equipment by translating the study into a practical dimension through the introduction of a case study in an integrated simulated working environment. Further, the phase seeks to establish a comparative analysis by cross-referencing the data obtained through the eye tracking device with gold standard subjective methods.

- Compare the data obtained by pupillometry with results from subjective methods such as questionnaires.
- Cross-reference the results to evaluate the accuracy and feasibility of the proposed methodology against established standards.

The goal is to validate the methodology's accuracy and viability against established standards, laying a robust foundation for subsequent real-world application.

- Validate the accuracy and effectiveness of the methodology in a controlled laboratory environment.
- Establish reference standards for comparison with the results of future studies.
- Prepare the groundwork for implementing the methodology in industrial settings, aiming to enhance understanding and management of occupational determinants of CFPW.

Through these objectives, the research aims to contribute valuable knowledge to the field of the determinants of CFPW assessment by offering a methodologically sound approach for evaluating them in occupational settings, providing insights into the applicability and effectiveness of pupillometry in assessing determinants of CFPW, and enhancing understanding and management of occupational determinants of cognitive function and psychological well-being to promote employee well-being and optimize workplace environments.

1.3 Dissertation structure

This thesis begins with an introduction to the fundamental concepts, starting with anatomy of the eye, the presentation and physiological mechanisms of the determinants of CFPW and their effect, ending with concepts of eye-tracking. Then, linking to the relevant state-of-the-art, the theory section is concluded. In this section, subjective and objective approaches for estimating the determinants of CFPW presented before are thoroughly reviewed.

The analytical part of the thesis is then divided into two different practical stages, each containing respectively methodology, results, discussion, and conclusion. These stages are the validation of the Pupil Labs Core eye-tracking glasses and an experimental laboratory simulated working environment tests.

2 Fundamental Concepts

This chapter is composed by five subchapters. In short, an exploration of fundamental concepts is provided, which is essential for a comprehensive understanding of the research. Initially, the human eye is explored, covering aspects such as its structure and functions. Furthermore, the pupil is examined with more emphasis, by investigating its functions, control mechanisms, and factors influencing it, such as illumination.

The chapter then moves on to an exploration of the determinants of CFPW, specifically workload, fatigue, attention and occupational stress, acknowledging that certain determinants may serve as both the cause and effect of others. These are explored in order to understand their unique impact in occupational settings. Therefore, a discussion of the resultant effects of these determinants on workers and in the workplace follows. Respectively, in mental (anxiety, depression, burnout) and physical (fatigue, musculoskeletal problems, heart disease) health, as well as absenteeism, turnover, and overall productivity.

Finally, the chapter explores into the field of eye tracking, examining several measures and their applications in monitoring visual activity. It analyses many types of eye tracking metrics and their utilization.

These fundamental concepts will serve as a robust foundation for the specific research on occupational determinants of CFPW. As it provides a detailed understanding of how these elements intertwine and influence the well-being and performance of individuals in the workplace.

2.1 Human eye

Concerning the visual system, the term "eyeball" is inclusive, covering not just the eye but also its associated components (Raquel, 2022). Consequently, the examination will encompass the ocular adnexa (Figure 1) as well as the anterior and posterior structures of the eye (Figure 2). Vision, being the most relied-upon sense for understanding the world, has a more extensive scientific foundation compared to the other senses. This is primarily due to the emphasis on research and understanding directed towards the major organ responsible for vision, the eye (Armstrong and Cubbidge, 2019).

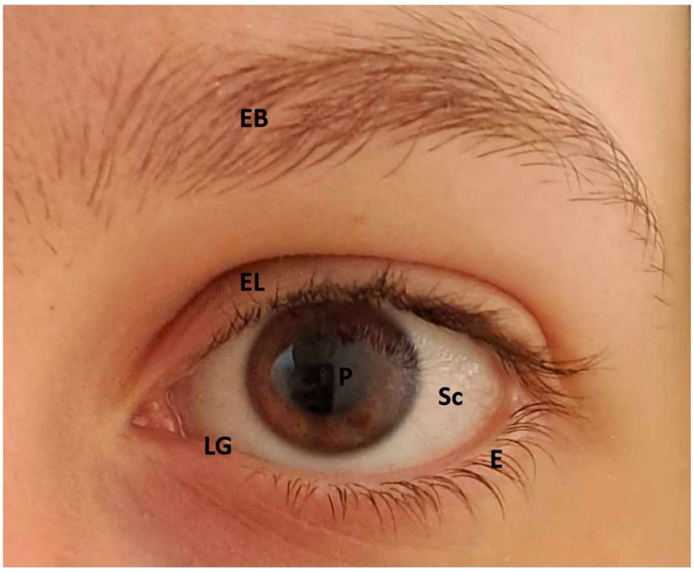

Figure 1 – Human eye. E – eyelashes; EB – eyebrowns; EL – eyelid; L – lacrimal gland; P – pupil; Sc – Sclera. [Original image]

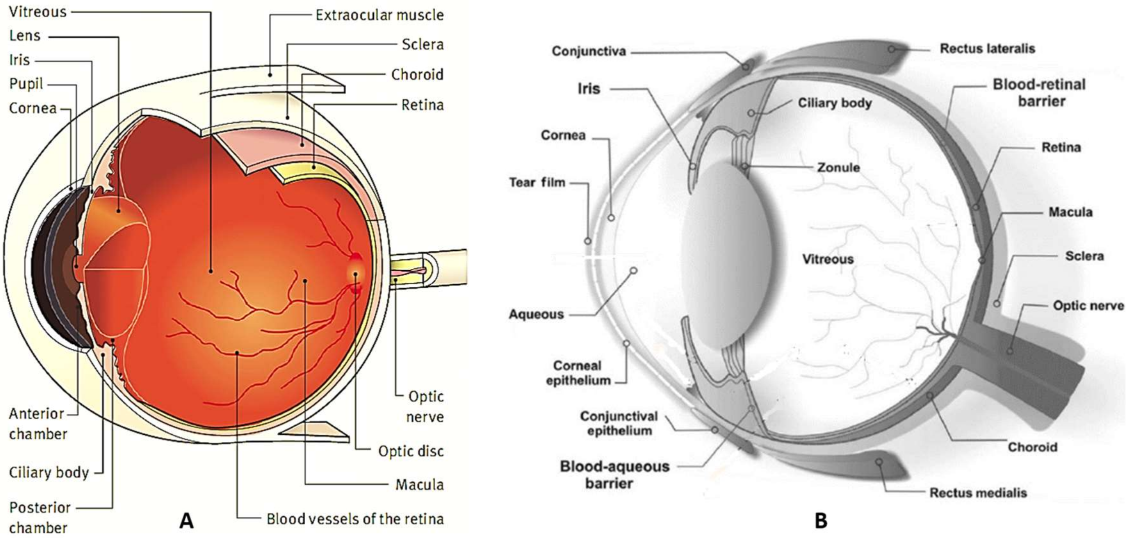

Figure 2 – Anatomy of the eye. A – Three-dimensional diagram adapted from Presland & Myatt (2010). B – Sagittal scheme adapted from Willoughby et al. (2010).

The human eye, approximately spherical and measuring 25mm in diameter with a volume of 6.5 mL, possesses an average axial length of 24 mm (with a range of 21–26 mm). It is, in fact, composed of two spheres, with the cornea representing the anterior aspect and exhibiting a greater curvature than the posterior sclera. This distinction leads to the functional division of the eye into two regions: the anterior eye and the posterior eye (Armstrong and Cubbidge, 2019).

The ocular adnexa pertain to the supplementary or neighbouring components of the eye, including structures such as eyebrows, eyelids, eyelashes, lacrimal gland, and orbit. The anterior segment includes the cornea, iris, ciliary body, crystalline lens, aqueous humour, and the anterior part of the sclera. Finally, the vitreous body, choroid, retina, and optic disk compose the majority of the eye's posterior segment (Armstrong and Cubbidge, 2019).

2.1.1 Ocular Adnexa

Firstly, the eyebrow, characterized by a thickened skin area with hairs directed upward and toward the temporal side, serves a dual function. Notably, it prevents forehead sweat from entering the eyes and contributes to facial expressions. Moving to the eyelids, these movable skin folds act as protective barriers against airborne particles and regulate light entry. Additionally, they play a crucial role in tear composition. Rows of eyelashes on both upper and lower lids, around 150 on the upper and 75 on the lower, offer protection against small particles but increase vulnerability to bacterial infections, known as "blepharitis." (Armstrong and Cubbidge, 2019).

Shifting the focus to the lacrimal gland, situated within the eye socket above the eye, it plays a pivotal role in ocular defence. Split into orbital and palpebral portions, the gland releases tears containing defence elements like lysozymes and immunoglobulin A. Excess tears follow canaliculi into the lacrimal sac and eventually the nasal cavity. Now, considering the orbit, a bony socket housing the eye, which comprises seven bones and is crucial for eye protection. Positioned anteriorly, closer to the lateral surface and the orbit's roof, it acts as an anchoring point for extraocular muscles and ocular tissues (Armstrong and Cubbidge, 2019).

Lastly, six extraocular muscles, connected to the eye by tendons at the sclera, facilitate 360 degrees of gaze coordination. Notably, this prevents double vision (diplopia) by ensuring synchronized movement. Furthermore, there are four rectus muscles – medial, lateral, superior, and inferior – attached to a common tendon ring (annulus of Zinn) at their posterior ends, linked to the orbit's posterior surface. The medial rectus moves the eye nasally, while the lateral rectus moves it temporally. Additionally, the superior rectus elevates the eye, and the inferior rectus lowers it. Moreover, the two remaining muscles, the superior and inferior oblique muscles, are inserted more "obliquely" into the upper and lower posterior temporal quadrants of the orbit. Notably, their primary actions include pulling the eyes upward or downward. Nevertheless, only the primary muscle actions have been described, and several of the muscles act in concert to produce secondary and tertiary actions. These actions move the eyes in more complex directions. Additionally, the study of the muscle action of the eyes and the coordination of eye movement is termed "binocular vision" (Armstrong and Cubbidge, 2019).

2.1.2 Anterior Structures of the Eye

In the first instance, the conjunctiva, an outer eye membrane, covers the white sclera and seamlessly extends from the cornea onto the upper and lower lids. This mucous membrane, with a nonkeratinized, stratified epithelium and subepithelial layers of adenoid and connective tissue, is notably susceptible to infections, often referred to as "conjunctivitis" (Armstrong and Cubbidge, 2019).

Moving to the cornea, which stands as the eye's foremost structure, it constitutes approximately one-sixth of the globe's circumference. Transparent and curved, the cornea continually refracts light, allowing it to focus on the retina. The cornea's primary thickness comprises regularly arranged collagen fibres, ensuring transparency by contrast to its smooth epithelium and absence of blood vessels (Armstrong and Cubbidge, 2019; Raquel, 2022).

Beyond the cornea lies the sclera, which forms the outermost layer of the eye, except for the cornea. It exhibits varying thickness, with its posterior region being the thickest and the point of attachment for extraocular muscles being the thinnest. Unlike the cornea, the sclera's irregularly arranged collagen fibres impart an opaque appearance. Functionally, the sclera provides crucial support, protection, and anchorage for intra- and extraocular structures, including the musculature, maintaining the eye's shape (Armstrong and Cubbidge, 2019; Raquel, 2022).

Furthermore, transitioning to the iris, a 12-millimeter-diameter structure, serves the dual role of regulating light entering the eye and dividing it into anterior and posterior chambers. Analogous to a camera diaphragm, the iris contains pupil size, a crucial aspect influenced by the autonomic nervous system (ANS) (Armstrong and Cubbidge, 2019; Raquel, 2022). The anterior surface of the iris has a distinct division into two concentric zones—the peripheral ciliary zone and the central pupillary zone, marked by the collarette ridge. The stroma beneath the anterior epithelium reflects its vascular arrangement through radial furrows and ridges. The pupillary sphincter, located within the stroma adjacent to the pupil, orchestrates pupil constriction, forming a concentric muscular ring up to 1 mm wide (Bouffard, 2019). The iris contains melanin-rich cells on its posterior surface, preventing light penetration. The iris's diverse pigment levels dictate its colour, with less pigment yielding blue and progressively more pigment resulting in green, hazel, and brown eyes (Armstrong and Cubbidge, 2019).

Moreover, moving deeper into the eye, the ciliary body, a 5–6 mm-wide ring of tissue, extends from the scleral spur anteriorly to the ora serrata posteriorly, forming the anterior continuation of the choroid. This intricate structure consists of the ciliary muscle and tissues responsible for secreting aqueous humour. Additionally, it provides attachment points for zonular fibres, which connect to the crystalline lens periphery, enabling lens position maintenance. Controlled by the oculomotor nerve, the ciliary body plays a vital role in the eye's ability to change power and focus, a process known as "accommodation" (Armstrong and Cubbidge, 2019; Raquel, 2022).

Additionally, adjacent to the ciliary body, the crystalline lens, composed of specialized surface ectoderm cells, is a highly elastic, circular, biconvex, transparent body located immediately behind the pupil. Suspended from the ciliary body by zonular fibres and enclosed within a transparent capsule, the lens possesses less refractive power than the cornea. The ciliary muscle contraction during accommodation relaxes zonular fibre tension on the lens, causing it to bulge and increasing its thickness and refractive power. This variable power facilitates focusing on distant and near objects in the visual scene (Armstrong and Cubbidge, 2019; Raquel, 2022).

Furthermore, the eye's aqueous humour, a transparent liquid produced by the ciliary body, fills the anterior chamber, passing through the pupil. This fluid passes through the trabecular meshwork into Schlemm's canal, draining into the venous system. Functioning like water, the aqueous humour provides nutrients to the cornea and crystalline lens, both devoid of a blood supply. The continuous production and drainage of aqueous humour maintain fluid pressure, ranging from 10 to 20 mm of mercury, to uphold the eye's shape (Armstrong and Cubbidge, 2019; Raquel, 2022).

To summarize, the interconnected structures of the eye, from the conjunctiva to the aqueous humour, contribute to its complex functions, encompassing protection, vision regulation, and maintenance of structural integrity. In addition, it is worth noting that the exploration of the pupil will be delved into in subsequent sections.

2.1.3 Posterior Structures of the Eye

With regards to the posterior structures of the eye, the vitreous cavity, resembling a clear gelatinous expanse, comprises about two-thirds of the eye's volume, gently cradling its form. This fluidic sanctuary, loosely tethered to the retina, embodies transparency, with a dense cortical zone of collagen fibres enveloping a liquid core. Described as a blend of water, salts, and collagen, this vitreous essence remains constant, occasionally giving rise to floaters—whirling particles perceived in the visual panorama—by virtue of circulating collagen fibre congregations (Armstrong and Cubbidge, 2019).

Transitioning to the choroid, a vibrant layer between the sclera and retina, its deep chocolate hue, courtesy of melanin pigmentation, absorbs stray light, creating a dynamic interplay of light and colour. Serving as both a visual backdrop and a nutritional conduit, the choroid pulsates with life, fostering the retinal photoreceptor cells (Armstrong and Cubbidge, 2019; Raquel, 2022).

Further within, the retina, akin to a high-resolution camera sensor, unfolds its layers with intricate precision. Like a symphony, rods and cones harmonize, translating light into nerve symphonies for the brain's auditory delight. The macula, a visual maestro, orchestrates visual acuity akin to a pixel-packed image, with its fovea centralis spotlighting the crescendo (Armstrong and Cubbidge, 2019; Raquel, 2022).

The optic disk, a blind spot devoid of rods and cones, acts as a gateway for the lifeblood of the retina, revealing tales of hypertension and diabetes. The retina, a delicate tapestry easily unravelled by trauma, whispers stories of its resilience and fragility, a dynamic narrative within the ocular cosmos (Armstrong and Cubbidge, 2019; Raquel, 2022).

2.1.4 Pupils

Situated between the cornea and the lens and encircled by the iris, the pupil is pivotal in regulating light entry into the eye. The intricate regulation of pupil diameter involves both the parasympathetic and sympathetic components of the ANS (Zele and Gamlin, 2020). Two sets of muscles are involved: the sphincter muscles, which cause miosis, reduce diameter, while the dilator muscles, linked to mydriasis, increase it (Bouffard, 2019). Parasympathetic neurons impact the sphincter pupillae muscle, inducing constriction, while sympathetic counterparts target the dilator pupillae muscle, prompting dilation (Zele and Gamlin, 2020; Pinheiro and da Costa, 2021). This intricate interplay is crucial for adjusting the pupil's aperture based on environmental lighting and visual demands (Bouffard, 2019).

Additionally, the pupillary dilator comprises fibres arranged in a radial pattern encircling the pupil, extending beneath the stroma's entire underside. This configuration separates it from the pigmented layer on the back of the iris, forming the pupillary ruff—a dark ring often noticed distinguishing the iris from the pupil. The visibility of the ruff fluctuates; it may vanish when the pupil is dilated, and its diameter maximizes during pupil constriction. The constriction pulls the ruff forward, making it visible from the iris's posterior surface (Bouffard, 2019).

Pupil dilation primarily increases light intake, while constriction reduces it. Therefore, pupil light reflex (PLR) is a known and studied process. However, the pupil is also influenced by other factors, including cognition, sleep, and arousal (Zele and Gamlin, 2020). Table 1 presents the alterations in pupil size associated with various determinants of CFPW, according to the corresponding references. In addition to the factors previously mentioned, pupil size can also be affected by gender and age (Guillon *et al.*, 2016; El Haj, Boutoleau-Bretonnière and Chapelet, 2023).

Table 1 – Impact of occupational determinants of cognitive function and psychological well-being (CFPW) on pupil size.

Determinants of CFPW	Impact on pupil size	References
Workload	Dilation	(Ferreira *et al.*, 2024)
Fatigue	Constriction	(Bafna and Hansen, 2021)
Attention	Dilation	(Joshi and Gold, 2020)
Stress	Dilation	(Ferreira *et al.*, 2024)

Notwithstanding there is a difference worth mention in pupil size metrics. Tonic pupil size is the average size of the pupil within a pre stimulus baseline or while at rest, which is often measured over a few minutes. On the other hand, an alteration in pupil size compared to a baseline measure and in reaction to a task-relevant event or stimulus is called phasic pupil size. A larger tonic pupil diameter could suggest increased stress or hyperarousal, while a smaller tonic pupil diameter might indicate feelings of fatigue, boredom, or low engagement with a task. Also, a larger phasic pupil diameter could suggest heightened arousal, stress, or increased workload (Pauszek, 2023).

The following sub-chapter provides a more in-depth explanation of how illumination affects the pupil.

2.1.5 Eye movements and visual attention

The eye performs various movements, including vergence and torsional actions. However, for this research, the primary focus is on fixations, saccades, smooth pursuit, scan paths and blinks. Visual attention is also defined.

2.1.5.1 Blinks

Blinks are involuntary actions involving the opening and closing of the eyelids, necessary for spreading a thin fluid film called the "precorneal tear film" over the frontal part of the cornea (Kishore Kumar and Narayanam, 2021). This process facilitates the diffusion of liquids across the corneal surface (Wang, Lv and Zheng, 2018). Blinking is characterized by rapid eye movements induced by the orbicularis muscle (Wang, Lv and Zheng, 2018). Factors such as cognitive workload, fatigue, and arousal can influence blink rate (Cao *et al.*, 2021). On average, blinks typically last between 100 and 400 milliseconds (Wang, Lv and Zheng, 2018).

2.1.5.2 Smooth pursuit

Pursuit movements are engaged when visually tracking a moving target, enabling the eyes to synchronize their velocity with that of the target based on its speed and range of motion (Duchowski, 2007f).

2.1.5.3 Saccades

Saccades are rapid eye movements crucial for gathering visual information as the eyes continuously shift to explore a scene (Kishore Kumar and Narayanam, 2021). These movements relocate the fovea, the area of the retina responsible for sharp vision, to points of interest within the visual field (Duchowski, 2007f; Wang, Lv and Zheng, 2018; Cao *et al.*, 2021). Typically lasting from 10 to 100 milliseconds, saccades involve coordinated motion of both eyes and are fundamental in directing attention to specific regions of interest (Wang, Lv and Zheng, 2018).

While saccades are often considered involuntary, they can also be voluntarily initiated, serving as both a reflexive response and a deliberate action. The term "saccade" originates from a French word meaning "flick of a sail," underscoring the swift and decisive nature of these eye movements. Although traditionally viewed as preprogrammed and unalterable once initiated, recent research suggests the possibility of feedback mechanisms guiding saccades in real-time, using internal representations of head, eye, and target positions rather than visual feedback. Despite debates regarding their underlying neural mechanisms, saccades are indispensable for navigating and comprehending the visual environment, facilitating rapid shifts in gaze direction to gather essential visual information (Duchowski, 2007f).

2.1.5.4 Fixations

Fixations denote static states in eye movement where the gaze remains fixed on a specific area within a visual scene (Kishore Kumar and Narayanam, 2021). In the context of human motion recognition systems, fixations are typically defined as the periods of time between consecutive saccades (Wang, Lv and Zheng, 2018). These fixation periods usually last from 100 to 200 milliseconds (Wang, Lv and Zheng, 2018). Fixations play a crucial role in directing attention and attraction to specific stimuli within the visual field (Cao *et al.*, 2021).

Contrary to common belief, fixations are not solely controlled by the same neuronal circuit responsible for smooth pursuits but instead involve miniature eye movements such as tremors, drifts, and microsaccades. Microsaccades, characterized by small, spatially random movements varying in amplitude from 1 to 2 minutes of arc, contribute to the maintenance of fixation stability. Interestingly, artificially stabilizing an image on the retina leads to vision fading within approximately one second, underscoring the intricate nature of fixations within the visual processing system (Duchowski, 2007f).

2.1.5.5 Scan path

A scan path is a sequence of trajectories linking fixations and saccades, providing understanding of the spatial arrangement of eye movements and revealing individuals' interests and cognitive states during visual exploration (Cao *et al.*, 2021).

2.1.5.6 Visual attention

Visual attention, studied for over a century, spans psychophysics, cognitive neuroscience, and computer science. Early scholars like Von Helmholtz and James emphasized spatial and conceptual aspects ("where" and "what"), while Gibson introduced intention ("how"). These views shape contemporary understanding, defining visual attention as a cognitive process enabling selective focus, influenced by factors like perception, intention, and task demands. It operates in a cyclical process, switching between peripheral and foveal vision, yet does not fully address higher-level cognitive functions (Duchowski, 2007g).

2.2 Illumination

Regarding illumination, it is crucial to grasp the fundamental concepts. First, important vision concepts are explored. Next, radiometry and photometry are delved into, elucidating their respective units. Finally, the PLR and the significance of illumination in workplace settings, along with regulatory considerations, are discussed.

2.2.1 Visual aspects

The visual aspects of illumination discussed here include visual acuity, accommodation, and adaptation.

Foremost, the visual acuity (Figure 3A) refers to the eye's ability to recognize small objects distinctly and accurately, even when they are positioned close together. Quantitatively, it is the inverse of the minimum angle required for the eyes to distinguish a detail (EDP, 2016).

Briefly, eye adaptation (Figure 3B) involves adjusting to varying light levels, causing pupil dilation or constriction. In darkness, pupils widen, enabling better visibility but with reduced detail and colour perception. This process takes minutes, while adaptation to light occurs rapidly, within seconds (EDP, 2016).

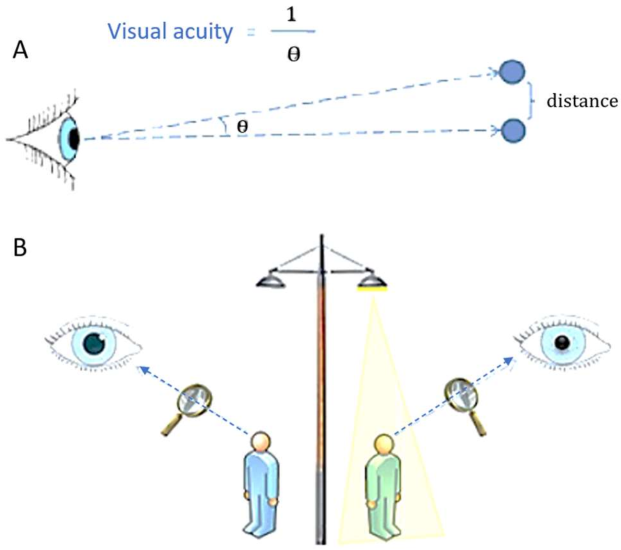

Figure 3 – A - Visual acuity. B - Pupil dilation in different ambient lighting conditions. Adapted from EDP (2016).

Finally, accommodation is an adaptive process of the eye, enabling it to project a sharp image onto the retina, whether the object is near or far (EDP, 2016). This ability primarily relies on the crystalline lens, whose dioptric power is variable. The process involves changes in the crystalline lens's (Figure 2A – *Lens*) curvature and thickness, controlled by the ciliary muscle and zonular fibres (Raquel, 2022). When viewing distant objects, the lens flattens, reducing its refractive power. For close-up tasks, like reading, the lens thickens and curves, enhancing its refractive power. This dynamic process ensures clear vision across different distances (EDP, 2016; Raquel, 2022).

2.2.2 Radiometry and photometry

The human eye responds to light wavelengths between 360nm and 800nm (Bonmati-Carrion *et al.*, 2016; Raquel, 2022), with radiometry and photometry being essential concepts in lighting discussions. Radiometry describes and measures electromagnetic radiation propagation across all frequencies, while photometry is a subset dedicated solely to visible light as detected by humans. Radiometric quantities include radiant flux, irradiance, radiant intensity, and radiance, while their photometric equivalents are luminous flux, illuminance, luminous intensity, and luminance. While radiometry pertains to physical light, i.e., the energy radiated, photometry relates to light perceived by humans, i.e., luminous energy as received by our eyes. Thus, "light" describes electromagnetic radiation in the visible spectrum, while all other spectrums are simply defined as "radiation" (Raquel, 2022).

The radiant flux measures the energy transferred through an area over time. Radiant intensity accounts for the flux per unit angle incident from or emerging from a point and propagating in a specific direction. Irradiance is the flux density per unit area incident at or emanating from a point on a given surface. Radiance is the angular flux density, the flux per unit angle incident and per unit area, passing or emerging from a specific point on a specific surface with a specific direction of propagation. Luminous flux is the amount of light emitted or received, measured in lumens, and luminous intensity is a measure of a source's ability to emit light in a particual direction, expressed in candelas. This measure is useful since most light sources do not have the same luminous flux in all directions, therefore not having a uniform luminous intensity. Illuminance is the luminous flux per square meter, represented in lux (lumen(lm)/m^2), while luminance is the light reflected by a surface in a given direction per square meter of illuminated area, measured in candela (cd)/m^2. In other words, illuminance pertains to the amount of light projected onto a specific surface, whereas luminance represents the light reflected by that surface at a given angle, perceived by the eyes (Raquel, 2022). Figure 4 shows a schematic diagram of radiometric and photometric units (EDP, 2016).

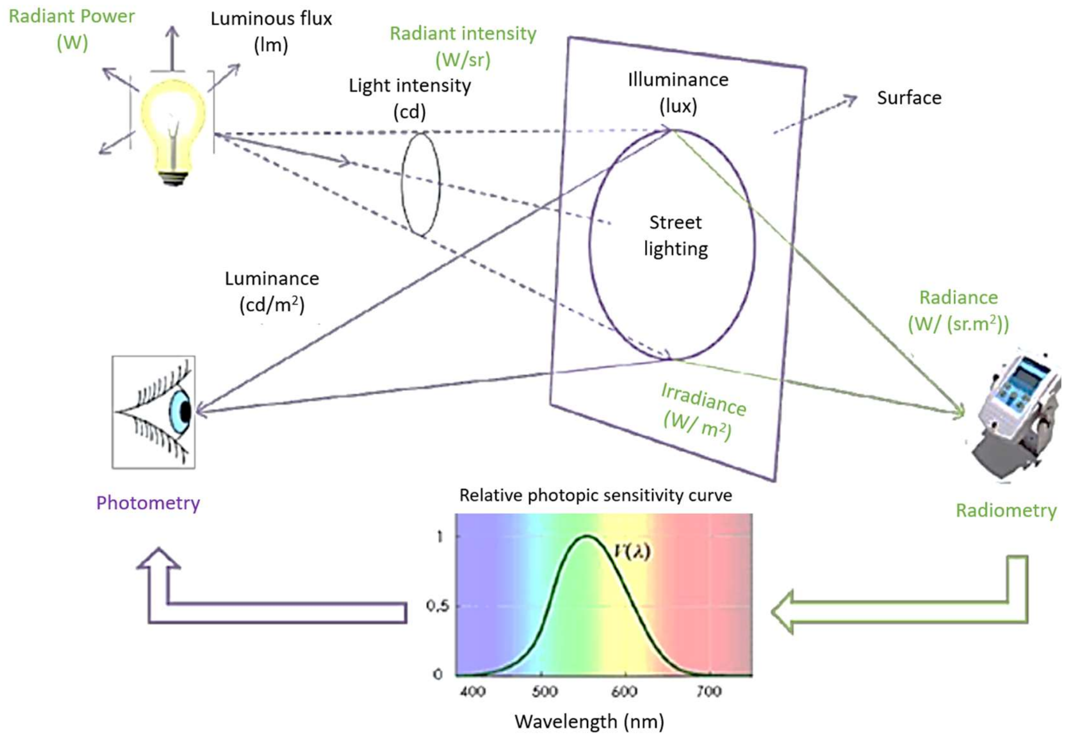

Figure 4 – Parallelism of concepts associated with Radiometry and Photometry. Adapted from EDP (2016).

2.2.3 Pupil light reflex

When pondering alterations in pupil size, the primary thought often revolves around the PLR, which refers to the pupil's contraction when exposed to heightened illumination (Vilotijević and Mathôt, 2023). Upon the activation of a light stimulus, a rapid constriction of the pupil occurs, swiftly reaching its smallest size (maximum constriction). This initial quick reaction is followed by a gradual dilation (escape), maintaining a partially constricted state until the light stimulus concludes (Bonmati-Carrion *et al.*, 2016).

The PLR involves three types of retinal cells: rods and cones for rapid adjustments, and intrinsically photosensitive retinal ganglion cells (ipRGCs) for slower, sustained responses (Bouffard, 2019). The ipRGCs contain the light-sensitive melanopsin photopigment. These cells transmit light signals through their axons to the olivary pretectal nucleus, a key brainstem region controlling the PLR. This neural pathway highlights the crucial role of ipRGCs in adjusting pupil size in response to changes in environmental light (Bonmati-Carrion *et al.*, 2016).

In addition, the near reflex regulates ocular adjustments for near vision, involving miosis, convergence, and accommodation. Supranuclear control includes cortical areas and midbrain nuclei coordinating signals for pupil constriction, lens accommodation, and eye convergence via the Edinger-Westphal nuclei and third cranial nerve subnuclei (Bouffard, 2019).

In sum, the pupil constricts in response to light and near vision stimuli, both activating the same anatomical pathway. Parasympathetic neurons in the Edinger-Westphal nucleus and the ciliary ganglion contribute, with the near reflex involving a larger proportion compared to the PLR, at a ratio of 30:1 (Bouffard, 2019).

2.2.4 Workplace lighting

Adequate workplace lighting is crucial as it is deemed a significant occupational hazard, potentially jeopardizing worker’s safety and well-being and increasing the likelihood of workplace accidents (ILO, 2014).

Thus, illumination is crucial for ensuring safe and healthy work environments, overseen by a Superior OSH practitioner. Inadequate lighting can negatively impact safety, satisfaction, and worker performance, leading to visual fatigue and other health issues (Katabaro and Yan, 2019; Kwong, 2020). The International Standard Organization (ISO) 8995:2002 defines recommended illuminance levels for different work activities, aiming to ensure worker’s safety and health (see Table 2).

Table 2 – Recommended illuminance values for the task area and surrounding area according to ISO 8995:2002. (U – illuminance uniformity)

Task area (Lux)	Neighbourhood area (Lux)
≥ 750	500
500	300
300	200
≤ 200	Same as task illuminance
$U = E_{min}/E_{medium} = 0{,}7$	$U = E_{min}/E_{medium} = 0{,}5$

Lastly, concerning the nature of light, studies suggest that exposure to blue light exerts the most potent non-visual influence (Berson, Dunn and Takao, 2002). Other research has indicated that blue light leads to heightened pupillary constriction (Takahashi *et al.*, 2010), promotes alertness, enhances cognitive function, suppresses melatonin production, and alters circadian rhythm phases (Chaveznava *et al.*, 2020).

2.3 Determinants of cognitive function and psychological well-being

The European Agency for Safety and Health at Work (EASHW) underscores that psychosocial risks arise from inadequate work design, organization, and management practices, as well as unfavourable social workplace environments. These factors can lead to adverse psychological, physical, and social outcomes. Examples include excessive workloads, conflicting demands, lack of decision-making authority, poorly managed organizational changes, job insecurity, communication issues, lack of support from management or peers, harassment, and interactions with challenging clients. These challenges contrast with stimulating environments offering autonomy, training, and positive social interactions (EU-OSHA, 2022).

As a consequence, organizations may face decreased performance, increased absenteeism and presenteeism, higher turnover rates, and elevated accident rates. Mental health-related absences tend to be prolonged and can contribute to higher rates of early retirement. The associated costs to businesses and society are substantial, running into billions of euros at the national level (EU-OSHA, 2022).

Given this context, the primary focus of the psychosocial risk factors in the workplace will centre on mental and cognitive risk factors. These include excessive workload, for example. However, worker's CFPW can be influenced by other factors, such as attention (Namian, Albert and Feng, 2018). Therefore, the selected determinants of CFPW for further analyses are workload, attention, fatigue and stress. It is important to note that certain determinants can act as both causes and effects for each other. Figure 5 outlines potential causes on the left and some preventive measures on the right. A brief overview of these determinants will be provided in the next subsections.

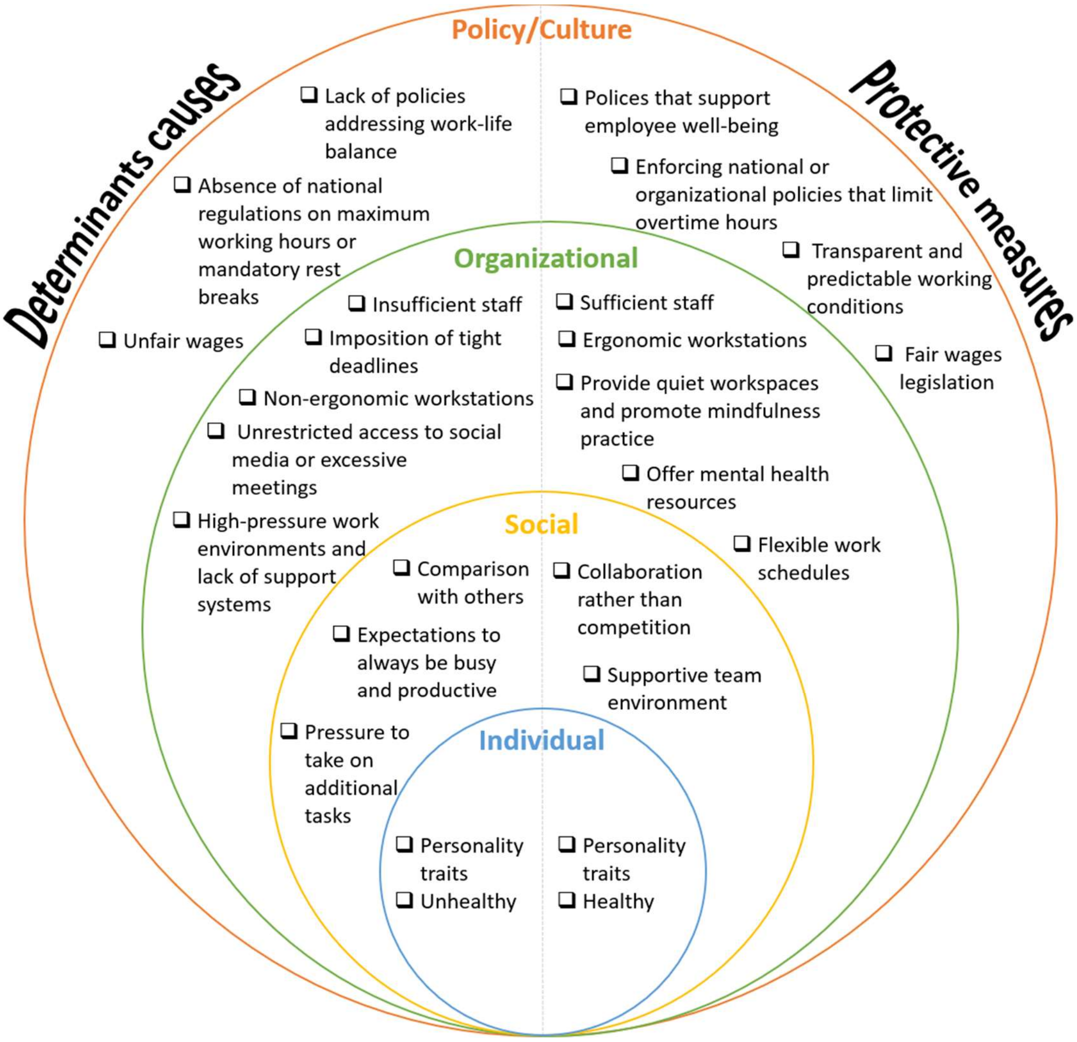

Figure 5 – Social-ecological model to illustrate the protective measures and causes for the occupational determinants of cognitive functions and psychological well-being.

2.3.1 Workload

Similar to many other concepts examined within psychology, there is no universally accepted definition for the term “workload” (Bowling and Kirkendall, 2012), as it is a complex construct (Kantowitz, 1987). However, it can be used as an inclusive term encompassing any factor that reflects the volume or complexity of one's tasks (Bowling and Kirkendall, 2012).

Given the broad scope of the workload concept, it is understandable that researchers have identified numerous dimensions and operationalized them in a variety of ways. For instance, workload has been delineated to encompass both quantitative and qualitative aspects, as well as mental and physical components (Bowling and Kirkendall, 2012).

2.3.1.1 Quantitative and Qualitative Workload

Quantitative workload pertains to the volume or quantity of tasks assigned to an individual. In contrast, qualitative workload focuses on the complexity or level of difficulty associated with those tasks (Bowling and Kirkendall, 2012).

To illustrate the distinction between quantitative and qualitative workload, two biomedical engineers were considered. The first engineer is tasked with reviewing and approving a large volume of routine paperwork related to equipment maintenance schedules. While the tasks themselves are straightforward, the sheer volume of paperwork creates a significant demand on the engineer's time and attention, reflecting high quantitative workload but low qualitative workload.

In contrast, the second engineer is assigned to develop a new medical imaging device, a task that requires advanced technical expertise and innovation. Despite having fewer tasks compared to the first engineer, the complexity and difficulty of designing a cutting-edge device make this assignment high in qualitative workload but low in quantitative workload.

Nonetheless, these workload classifications will not be used in future workload mentions.

2.3.1.2 Physical and Mental Workload

Forst of all, physical workload is typically characterized by uncomfortable or restricted body positions, exertion of high force, repetitive actions, insufficient rest periods, or a combination of these elements. These have been recognized as contributors to the development of musculoskeletal disorders associated with work (Hansson *et al.*, 2010).

With regards to mental workload, it is also sometimes referred to as cognitive load or mental demand (Naismith *et al.*, 2019). Various perspectives on mental workload exist, each contributing to a comprehensive understanding of this concept. While definitions may vary, it is important to note that these descriptions often overlap and complement each other rather than being entirely distinct. Mental workload can be viewed as the level of cognitive resources needed to execute a series of simultaneous tasks (Li *et al.*, 2020), the exertion of effort by the brain to accomplish tasks (Díaz-García *et al.*, 2021), the amount of brain activity within a unit of time, the rate of occupancy of brain resources, psychological pressure, and information processing capacity (Gu, Yin and Zhang, 2019; Qu *et al.*, 2020). Recognizing this overlap helps provide a holistic perspective on mental workload, acknowledging its multifaceted nature and the diverse factors that contribute to its measurement and impact on individuals.

Prolonged exposure to intense mental workload can lead to mental exhaustion (fatigue), reduced productivity, and potential adverse health consequences over time (Li *et al.*, 2020).

2.3.2 Fatigue

Fatigue, encompassing both a decline in performance and subjective sensations (Mounstephen and Sharpe, 1997), is a prevalent issue among the working population (van Dijk, 2003). This subjective experience is often characterized by feelings of weariness, lack of energy, and exhaustion (Mounstephen and Sharpe, 1997). The consequences of fatigue can be severe, resulting in decreased work effectiveness and an increased likelihood of errors and workplace accidents (Sadeghniiat-Haghighi and Yazdi, 2015; Zhang *et al.*, 2023) particularly when combined with long working hours and repetitive tasks (Naskrent *et al.*, 2022).

Occupational health concerns surrounding fatigue stem from its adverse consequences, particularly in more severe acute or chronic forms and when workers lack sufficient recovery opportunities. Among the adverse outcomes attributed to fatigue are poor performance, compromised service and product quality, and staff attrition. Moreover, fatigue is associated with an increased risk of depression, infectious and cardiovascular diseases (CVD), and disability, which can lead to prolonged absenteeism from work (van Dijk, 2003). In many work environments, employees face numerous risk factors that can combine to worsen fatigue (Zhu *et al.*, 2017).

Fatigue can be broadly classified into three categories: physical, which involves the muscles or peripheral nervous system; perceptual or visual; and cognitive or mental. Additionally, another form of fatigue, known as compassion fatigue, affects workers dealing with complex situations, such as mental health professionals (Tehrani, 2010; Singh *et al.*, 2020), human resources personnel, and police officers (Tehrani, 2010). Compassion fatigue arises from prolonged exposure to the narratives and experiences of distressed individuals, leading to symptoms similar to those experienced by the individuals being assisted (Tehrani, 2010).

Furthermore, excessive involvement and empathy with traumatic material increase the risk of developing secondary traumatic stress, which, when combined with burnout, is commonly referred to as compassion fatigue. Symptoms include persistent physical and emotional fatigue, detachment, irritability, and negative attitudes towards work and personal life. Mental health professionals affected by compassion fatigue may also experience self-doubt, diminished job satisfaction, psychosomatic issues, increased absenteeism, or substance misuse (Singh *et al.*, 2020).

However, this specific type of fatigue, which deviates from the study objectives, will not be elaborated on or examined further. While physical and perceptual fatigue will be addressed in subsequent sections, it is crucial to emphasize that the main focus of this study is on mental fatigue.

Additionally, sleep deprivation is a significant contributor to fatigue. Therefore, a subsequent chapter on sleep-induced fatigue was included to evaluate the impact of sleepiness.

2.3.2.1 Physical fatigue

Physical fatigue, whether neuromuscular or peripheral, involves a decline in muscular ability to carry out physical tasks effectively (Herlambang, Taatgen and Cnossen, 2019). This decline stems from reduced force generation activity, often linked to metabolic disorders or neuromuscular transmission failure. Consequently, this fatigue may result in decreased productivity or quality of performance (Yung, Manji and Wells, 2017).

2.3.2.2 Perceptual fatigue

This kind of fatigue shows up as a drop in visual or perceptual performance, along with heightened visual discomfort. It stems from extended periods of visual tasks rather than mental workload, which impacts arousal levels (Yung *et al.*, 2020). Some related symptoms may be eye fatigue, blurry vision, headache, light sensitivity, difficulty focusing, dryness in the eyes, diplopia (double vision) (Australia, 2021).

2.3.2.3 Mental fatigue

Cognitive or mental fatigue condition arises from the interplay of a psychobiological state with subjective, behavioural, and physiological manifestations resulting in diminished performance (Van Cutsem *et al.*, 2017; Díaz-García *et al.*, 2021; Proost *et al.*, 2022). It occurs as a consequence of prolonged engagement in excessively demanding and repetitive cognitive tasks over a sustained period (Rozand *et al.*, 2015; Pageaux and Lepers, 2018; Zhang *et al.*, 2023).

Mental fatigue is a widespread issue affecting individuals across various industries and nations, especially in professions like transportation (pilots and drivers) (Wise, Heaton and Patrician, 2019; Hu and Lodewijks, 2020), construction (Li *et al.*, 2019), and healthcare (Nielsen *et al.*, 2019). These fields often involve extended work hours in challenging environments, requiring constant concentration and vigilance to prevent accidents and injuries.

2.3.2.4 Sleep-induced fatigue

Sleepiness indicates the body's fundamental need for rest, often manifested through yawning, eye-rubbing, and nodding off. It results from the interplay of both homeostatic mechanisms and circadian rhythms. It is essential to monitor sleepiness to mitigate accidents, especially during monotonous tasks, driving, or nighttime shifts (Daguet, Bouhassira and Gronfier, 2019).

Sleep deprivation adversely affects cognitive functions like memory, attention, and decision-making. Prolonged focus feels mentally taxing, leading to decreased performance and intermittent microsleep episodes even in adequately rested individuals (Massar *et al.*, 2019).

Understanding sleepiness as a workplace hazard necessitates grasping circadian rhythms' role. These rhythms govern vital bodily functions, including sleep, regulated by an internal clock synced with light cues. For example, exposure to daylight promotes wakefulness, while darkness triggers melatonin release for restorative sleep. Disruptions, like jet lag or shift work, can lead to sleep disorders such as insomnia, affecting productivity and increasing the risk of chronic diseases (Suni and Singh, 2023).

Factors like late-night screen exposure or irregular meal schedules further disrupt this balance, impacting overall health. Prioritizing healthy sleep patterns by respecting circadian rhythms fosters restful sleep and supports overall well-being (Suni and Singh, 2023).

In situations like late-night shifts, implementing preventive measures is crucial for at-risk workers. This includes adequate rest breaks, shift rotation schedules, promoting sleep hygiene, and offering resources for managing stress and fatigue effectively. Educating workers about sleep prioritization and seeking professional help for sleep-related difficulties can also be beneficial (Suni and Singh, 2023).

2.3.3 Attention

Attention, a fundamental cognitive process, involves the selective focus on specific aspects of our surroundings while disregarding others. This ability to concentrate on relevant information is pivotal for effective task management, as errors are more likely when a task requires heightened attention (Sanjram, 2013). Therefore, in the workplace, the lack of attention can be considered a significant determinant of CFPW, contributing to stress and potentially leading to mental health issues such as depression (Mac Giollabhui *et al.*, 2019).

Transitioning to related concepts, it is important to distinguish between attention, alertness, and vigilance. While these terms are often used interchangeably, they represent distinct concepts in cognitive psychology. Alertness refers to the state of readiness that enables effective response to stimuli, playing a crucial role in daily tasks such as learning, problem-solving, and information recall, particularly in professions such as healthcare and manufacturing, where critical decision-making is essential (Tseng *et al.*, 2018). Vigilance, on the other hand, emphasizes the sustained maintenance of attention over time (Martin, Whittaker and Johnston, 2022).

In conclusion, attention, alertness, and vigilance are interconnected concepts crucial for effective task performance and workplace safety. By recognizing their distinctions and addressing their implications in the workplace, organizations can foster a culture that prioritizes employee well-being and productivity. Furthermore, another pertinent concept is hyperfocus, which denotes a state of deep concentration on a task, often leading to the exclusion of external stimuli. This phenomenon is commonly linked to conditions like autism, schizophrenia, and Attention Deficit Hyperactivity Disorder (ADHD). However, research on its effects on cognitive and neural functions is limited (Ashinoff and Abu-Akel, 2021). Therefore, attention-related disorders (ARDs) may be pertinent when studying one's attention.

ARDs encompass a range of neurodevelopmental conditions that challenge an individual's capacity to concentrate, sustain attention, and regulate impulses. These disorders pose obstacles to learning, employment, and interpersonal connections. Relevant examples include anxiety, depression, ADHD, Attention Deficit Disorder (ADD) and Obsessive-Compulsive Disorder (OCD). Adults with ADHD commonly encounter difficulties at work stemming from the cognitive requirements associated with the disorder. ADHD continues into adulthood, impacting roughly 1.2–7.3% of the global adult population. Challenges related to work performance and the heightened likelihood of job loss are often associated with ADHD symptoms, especially inattention. It is advisable to implement clinical interventions and employ objective evaluations of work performance (Fuermaier *et al.*, 2021). OCD is an anxiety disorder characterized by recurrent thoughts (obsessions) and behaviours (compulsions), which can significantly disrupt daily functioning. However, due to a lack of awareness among employers and coworkers about OCD and its treatments, the work environment can become hostile for those affected. This lack of understanding may lead to reprimands, termination, absenteeism, and decreased productivity. Despite being a treatable mental disorder, scepticism about classifying OCD as a disability persists (Neal-Barnett and Mendelson, 2003).

2.3.4 Occupational Stress

Work-related stress poses a significant challenge to occupational health and safety globally (EU-OSHA, 2015). Thus, occupational stress can impact the safety and well-being of workers. It adversely affects the performance of operators, resulting in decreased productivity, satisfaction, and adverse effects on both mental and physical health (Sarafis *et al.*, 2016). This, in turn, contributes to a rise in workplace accidents (Ventiv Technology, 2023).

While challenges at work can be motivating, excessive and prolonged pressure beyond one's coping abilities leads to stress (EU-OSHA, 2015, 2022). Distinguishing between 'good' stress from challenges and 'bad' stress is crucial. Stress is defined as a negative psychological state with cognitive and emotional components, influenced by environmental factors and organizational stressors (EU-OSHA, 2015).

Stress reactions at work encompass cognitive, emotional, behavioural, and physiological responses (EU-OSHA, 2015). These can lead to mental health issues like burnout, anxiety, and depression, as well as physical health problems such as cardiovascular disease or musculoskeletal disorders (van Dijk, 2003; EU-OSHA, 2022). Persistent stress resulting from exposure to risk factors like high workload can lead to chronic health problems. Individual traits influence coping abilities, while organizational healthiness impacts productivity, morale, and absenteeism. Stress, in turn, can further exacerbate reduced attention, creating a cyclical effect (EU-OSHA, 2015). Stress can either result from exposure to other risk factors or act as a risk factor itself.

The 4th European Working Conditions Survey revealed varying levels of work-related stress across European union (EU) member states, with notable prevalence in Greece, Slovenia, Sweden, and Latvia. The annual cost of work-related stress in the EU is approximately 20000 million euros, with significant economic impacts at national levels, such as Germany and the United Kingdom. Poor work management and organization contribute to stress, highlighting the importance of addressing psychosocial hazards in the workplace (Ventiv Technology, 2023).

Current stress theories emphasize the dynamic interaction between individuals and their environment, highlighting the role of psychosocial and organizational factors. Four prominent theories include Person-Environment Fit, Job Demand-Control (JDC) (Support), Effort-Reward Imbalance, and Transactional Models (Ventiv Technology, 2023).

2.3.4.1 Person-Environment Fit Theory

Originating from the University of Michigan, the Person-Environment Fit theory emphasizes the match between individual skills and workplace demands, identifying three forms of misfit: demand exceeding ability, unmet needs, or both (Rauthmann, 2021; Ventiv Technology, 2023).

2.3.4.2 Job Demand-Control (Support) Theory

This model, dominated by the JCD framework, highlights job strain resulting from high demands and low control. It incorporates social support as a moderator and identifies iso-strain as a high-risk scenario (Portoghese *et al.*, 2020; Ventiv Technology, 2023).

2.3.4.3 Effort-Reward Imbalance Model

The Effort-Reward Imbalance model posits that stress arises from an imbalance between effort expended and rewards received at work. Non-reciprocity in the psychological contract can lead to emotional distress and health risks (Ren *et al.*, 2019; Ventiv Technology, 2023).

2.3.4.4 Transactional Model

Transactional models emphasize the dynamic interaction between individual perceptions and environmental demands. Stress results when perceived demands exceed perceived capabilities, with various factors influencing this assessment. This model considers both psychological and physiological manifestations of stress, accounting for individual differences and the complexity of the stress process (Putwain *et al.*, 2021; Ventiv Technology, 2023).

2.4 Effects of the determinants of cognitive function and psychological well-being

This chapter is structured to examine the scientific evidence regarding the impact of psychosocial factors on various dimensions of OSH. Specifically, it will delve into the effects of these factors on mental health, encompassing conditions such as anxiety, depression, and burnout, as well as their implications for physical health, including chronical fatigue, musculoskeletal problems, and the risk of heart disease. Additionally, the chapter will explore how psychosocial factors contribute to absenteeism and turnover rates in the workplace, as well as their influence on overall productivity and performance. Through an in-depth analysis of these dimensions, this chapter aims to provide valuable insights into the multifaceted effects of the determinants of CFPW on OSH.

2.4.1 On workers

The effects of occupational determinants of CFPW on workers encompass a range of mental and physical health challenges. In this section, we delve into an extensive examination of these issues, starting with the exploration of physical health effects, followed by an in-depth analysis of mental health consequences.

2.4.1.1 Musculoskeletal problems

Work-related musculoskeletal disorders (WRMSD) are characterized by discomfort, injury, or persistent discomfort affecting various bodily structures, including muscles, joints, tendons, ligaments, nerves, bones, and the circulatory system, often exacerbated by occupational hazards (Bernal *et al.*, 2015). Unlike sudden workplace injuries such as slips, trips, and falls, WRMSD develops gradually over time due to repeated exposure to diverse risk factors, leading to discomfort during work and even at rest (SDMS, 2016). This prevalent health concern significantly impacts Europe's workforce, affecting a substantial number of individuals (Bernal *et al.*, 2015). Furthermore, WRMSD are among the primary reasons for work time limitations or loss (SDMS, 2016).

Occupational determinants of CFPW have been identified as correlating with WRMSD in diverse occupational groups, such as nurses (Bernal *et al.*, 2015; Correia, Barros and Baylina, 2021), construction workers (Anwer *et al.*, 2021), and flight attendants (Lee *et al.*, 2008). In particular, exposure to heightened workloads (Devereux, 2002; Bernal *et al.*, 2015; Anwer *et al.*, 2021) and stress (Anwer *et al.*, 2021) has been pinpointed as contributory elements to discomfort or pain across various bodily regions, encompassing the lower back (Lee *et al.*, 2008), neck, shoulders, upper extremities (Devereux, 2002; Bernal *et al.*, 2015), knees, and other anatomical sites (Bernal *et al.*, 2015).

The exact mechanism of this relationship remains elusive, though several theories have been proposed. One theory suggests that psychological stress could lower a person's pain threshold, leading to heightened perception of WRMSD. Another theory proposes that increased psychological stress might alter task performance, potentially leading to greater biomechanical strain. A third theory suggests that poor psychological well-being could amplify perceived pain or disability through various cognitive and behavioural reactions (Anwer *et al.*, 2021).

2.4.1.2 Cardiovascular diseases

CVD stand as the primary contributor to mortality worldwide, claiming approximately 17.9 million lives annually. CVD encompass a spectrum of heart and blood vessel disorders, spanning from coronary heart disease and cerebrovascular disease to rheumatic heart disease and other related conditions. The majority of CVD-related deaths, exceeding four-fifths, stem from heart attacks and strokes (WHO, 2024a).

Heart attacks and strokes can often occur without warning signs of underlying vascular diseases. Common symptoms of a heart attack include chest pain or discomfort, often radiating to the arms, shoulders, jaw, or back. Additional signs may include breathing difficulties, nausea, dizziness, sweating, and paleness, with women potentially experiencing different symptoms. Meanwhile, strokes typically manifest as sudden weakness or numbness on one side of the face, arm, or leg, accompanied by confusion, speech difficulties, vision problems, dizziness, severe headaches, or loss of consciousness (WHO, 2024b).

On the other hand, rheumatic heart disease presents symptoms like shortness of breath, fatigue, irregular heartbeats, chest pain, and fainting. Rheumatic fever, if left untreated, can lead to rheumatic heart disease, showcasing symptoms such as fever, joint pain, swelling, nausea, stomach cramps, and vomiting (WHO, 2024b).

Finally, the coronary artery disease (CAD) also referred to as coronary heart disease or ischemic heart disease, arises due to the accumulation of plaque within the coronary arteries, which supply blood to the heart. This plaque comprises cholesterol deposits, leading to the gradual narrowing of the artery walls, a phenomenon known as atherosclerosis (CDC, 2021).

The association between psychological stress and cardiovascular conditions is recognized as a significant public health concern (Lavie *et al.*, 2011), with psychological factors influencing physiological mechanisms implicated in the advancement of CAD (Kop, 1999).

Workload-induced stress or occupational stress activates physiological systems like the ANS and hypothalamus-pituitary-adrenal (HPA) axis, resulting in increased heart rate (HR), blood glucose levels, and blood circulation activity. Chronic stress may contribute to adverse cardiovascular effects, potentially accelerating atherosclerosis and increasing the risk of cardiovascular events (see Figure 6). Indirectly, stress can lead to unhealthy habits such as smoking, poor diet, excessive alcohol consumption, and physical inactivity, further elevating other cardiovascular risk factors (Ervasti *et al.*, 2023).

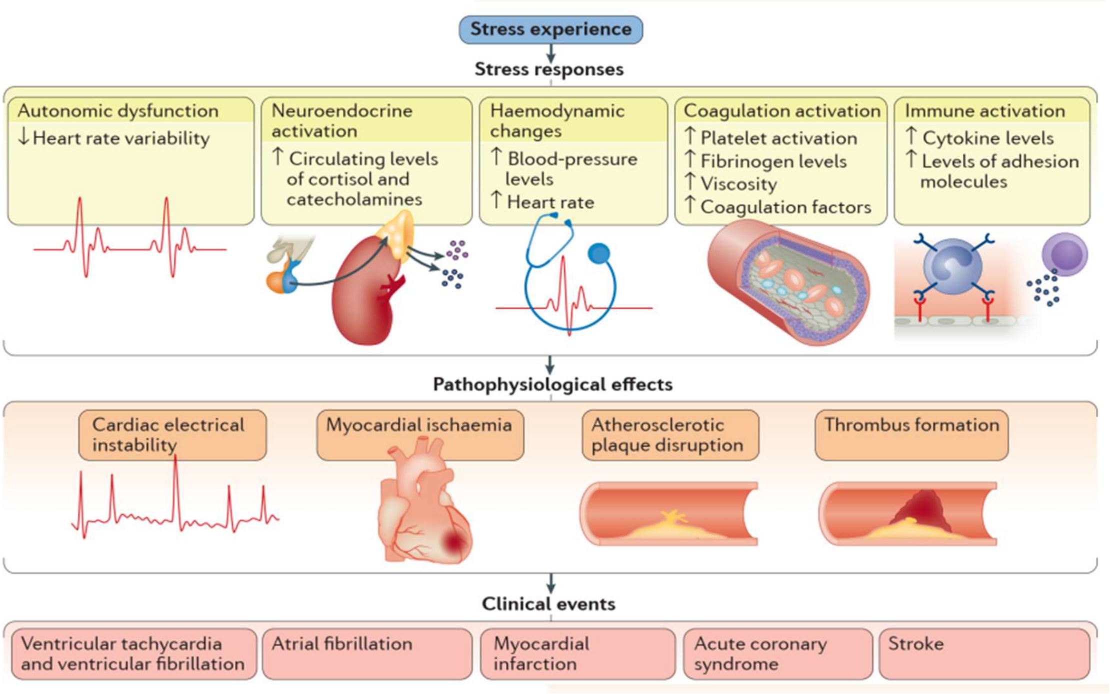

Figure 6 – A conceptual model of pathways from stress to preclinical pathophysiological changes and clinical CVD. Obtained from: Ervasti et al. (2023).

2.4.1.3 Burnout

Burn-out, considered an occupational phenomenon rather than a medical condition, arises from prolonged, unmanaged workplace stress. It encompasses three main aspects: feelings of depletion or exhaustion, increasing detachment from one's job accompanied by negativity or cynicism, and reduced professional effectiveness. It is important to note that burn-out is specific to the workplace and should not be applied to other areas of life (WHO, 2019).

2.4.1.4 Chronical fatigue syndrome

Chronic fatigue syndrome (CFS) also known as myalgic encephalomyelitis (ME) is a disabling illness characterized by overwhelming fatigue that is not relieved by rest. It often limits daily activities and affects cognitive functions, sleep, and pain. ME/CFS can lead to long-term disability, with many patients' bed- or house-bound for extended periods (CDC, 2023). While the exact cause of ME/CFS remains unidentified, researchers suggest that it may involve multiple underlying factors, leading to the illness in affected individuals (CDC, 2018).

Concerning psychological factors, stress affects the HPA axis, which regulates the body's response to stress and various physiological functions. Dysregulation of hormones like cortisol due to stress can disrupt immune response and exacerbate inflammation, potentially contributing to conditions like ME/CFS. While patients often report stress before illness onset, diagnosing or treating ME/CFS based on cortisol levels is challenging (CDC, 2018).

2.4.1.5 Headache

Headache is understood as a persistent condition characterized by sporadic episodes of pain that can last from minutes to days. Many patients experience these attacks at least once a month, leading to different levels of disability (Nicholson *et al.*, 2007).

Pain is defined as a psychological phenomenon involving the perception of unpleasant or aversive sensations. This perception involves the activation of multiple brain regions, creating a complex neuro matrix responsible for processing pain signals. Many of these brain regions are also implicated in other psychological processes such as attention and stress. Therefore, psychological factors may modulate pain by acting on these shared circuits, thereby altering the pain signal within the brain. Consequently, psychological factors have the potential to influence headache pain through various pathways within the central nervous system (Nicholson *et al.*, 2007).

2.4.1.6 Anxiety

Anxiety is characterized by feelings of worry, fear, uneasiness, or apprehension arising from a perceived lack of predictability, control, or attainment of desired outcomes in specific situations. These situations may range from concrete concerns like upcoming work evaluations or financial obligations to more abstract concerns such as career or family matters. Patients often use the terms "anxiety" and "stress" interchangeably, as they are closely related concepts. When individuals respond anxiously to stressors, they may become stressed about their response, leading to a cycle of heightened anxiety and stress (Nicholson *et al.*, 2007). Anxiety frequently correlates with high workloads and occupational stress (Battams *et al.*, 2014).

2.4.1.7 Depression

Depression, typically defined as a clinical condition, is characterized by persistent feelings of sadness, despair, emptiness, or loss of interest or pleasure in activities lasting for over a two-week period. While depression is considered a clinical disorder, everyone may experience temporary periods of sadness or loss of interest at some point in their lives (Nicholson *et al.*, 2007). Depression is commonly linked to high workloads and occupational stress (Battams *et al.*, 2014).

2.4.2 On the workplace

In 2017, EASHW conducted an international assessment of the financial impact of work-related accidents and illnesses. The costs associated with these incidents on a global and European scale are substantial (see Figure 7). Globally, the total cost amounted to 2,680 thousand of millions of euros. In comparison, the European cost was 476 thousand of millions of euros, which is proportionally lower than the global average. Both globally and in the EU, the distribution of costs between fatal and non-fatal cases is nearly identical, with each category contributing approximately half of the total costs (Elsler, Takala and Remes, 2017).

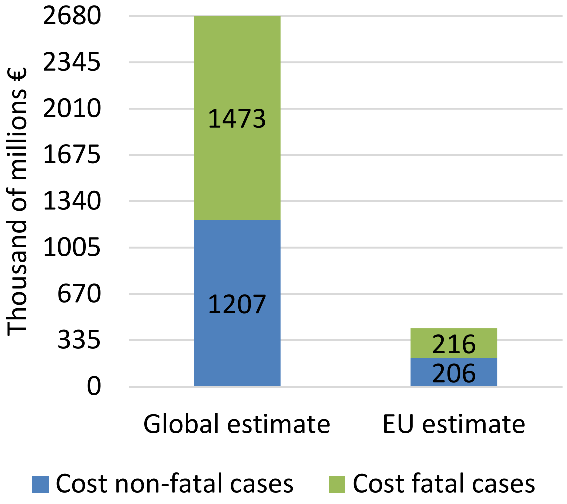

Figure 7 – Cost of work-related accidents and illnesses globally and in the EU. Adapted from: Elsler, Takala and Remes (2017).

The study calculated Disability-Adjusted Life Years (DALYs) for the primary causes of work-related mortality and morbidity across all EU countries. Figure 8A illustrates the percentage of DALYs attributed to various adverse health effects in the entire EU. Cancers are the leading cause, followed by WRMSD, circulatory diseases, and injuries. The "Others" category encompasses additional illnesses like mental health disorders or communicable diseases. For comparison the worlds percentage of DALYs is showed in figure 8B (Elsler, Takala and Remes, 2017).

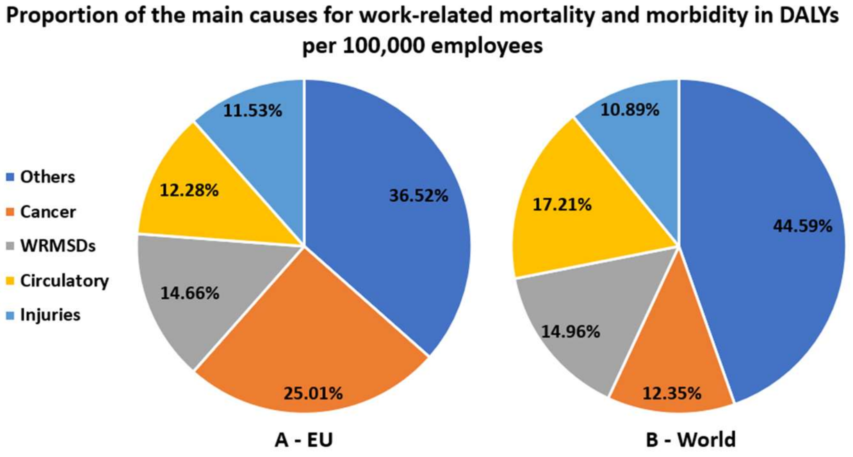

Figure 8 – The percentage of major causes for work-related mortality and morbidity in DALYs per 100,000 workers. A – in the European Union; B – in the world. Adapted from: Elsler, Takala and Remes (2017).

Nevertheless, figures 7 and 8 depict the cost estimate, which solely considers the reduced productivity stemming from lost work years. However, this calculation overlooks several other cost factors, including healthcare expenses, early retirement costs, and presenteeism (working while sick) (Elsler, Takala and Remes, 2017). Therefore, the actual figures, including both direct costs like worker's compensation and medical fees, and indirect costs like lost revenue, absenteeism, and expenses associated with hiring and training new employees (SDMS, 2016), may be significantly higher. For instance, WRMSD alone cost employers up to 17 thousand millions of euros (SDMS, 2016).

Given the significant expense estimates for employees and companies, it is crucial to introduce some pertinent definitions.

2.4.2.1 Absenteeism

Workplace absenteeism pertains to instances where employees are absent from work due to various reasons, including illness, occupational accidents, childcare responsibilities, or transportation challenges (NIOSH and CDC, 2024).

United States of America National Institute for OSH tracks absences reported by full-time employees attributable specifically to personal illness, injury, or medical conditions, termed as health-related workplace absenteeism (see Figure 9) (NIOSH and CDC, 2024).

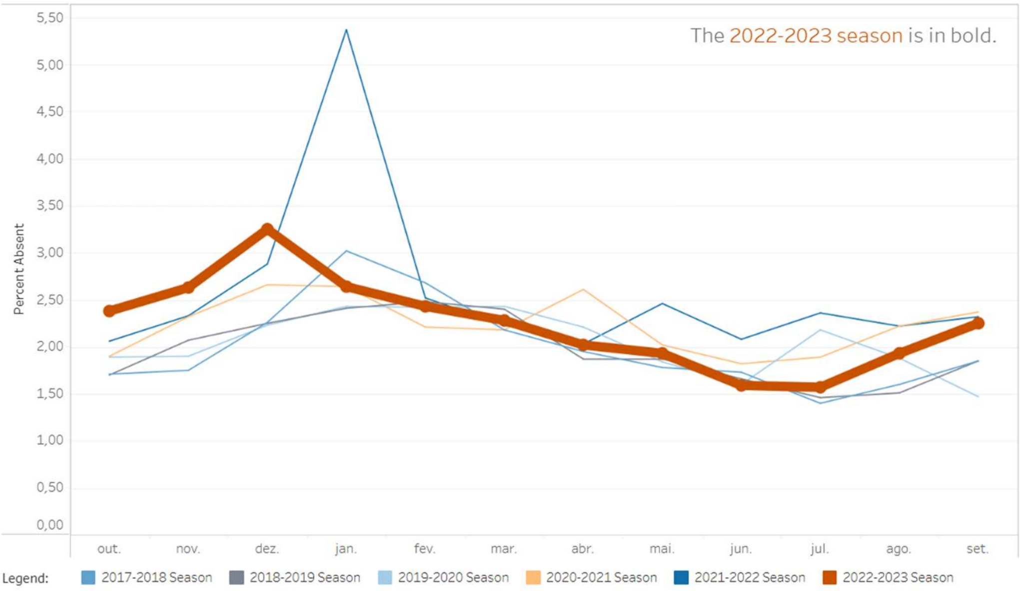

Figure 9 – Health-related Workplace Absenteeism among Full-time Workers in the United States. Adapted from: NIOSH (2024).

Before February 2020, absenteeism from work due to illness among EU members was depicted in Figure 10. The data illustrated an upward trend in absenteeism over time (WHO, 2023).

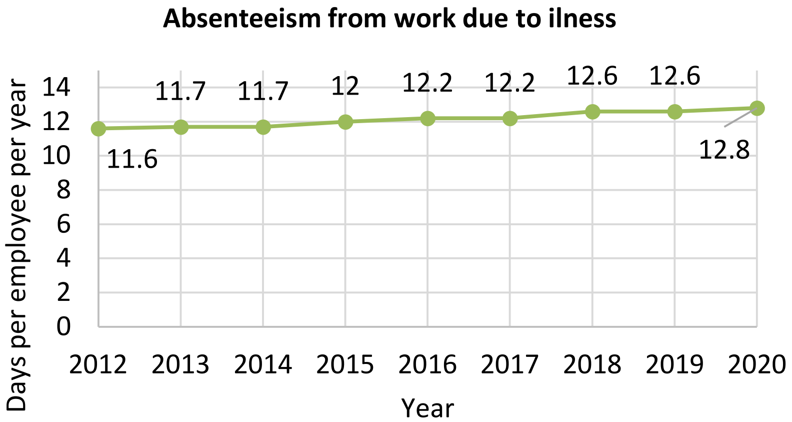

Figure 10 – Absenteeism from work due to illness, days per employee per year of the members of the European Union before February 2020. Adapted from: WHO (2023).

Additionally, Figure 11 depicts a bar chart illustrating the frequency of workplace accidents categorized by the number of days of absenteeism in 2020 and 2021. However, the extent to which determinants of CFPW contribute to these cases remains unclear.

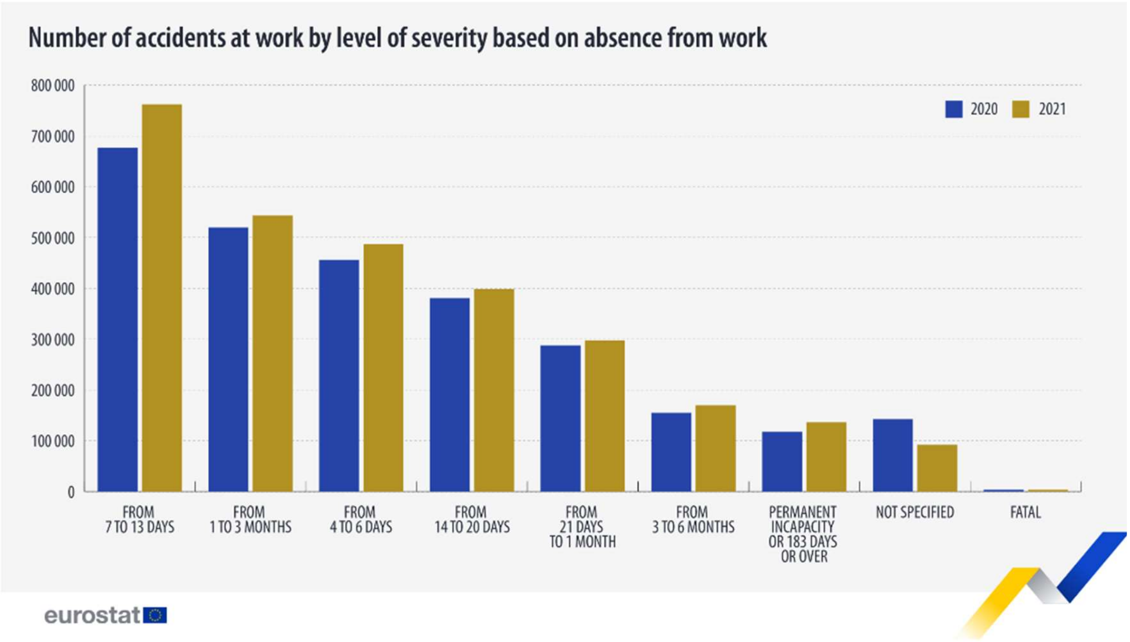

Figure 11 – Accidents at work by days lost. Adapted from: Eurostat (2023).

2.4.2.2 Turnover

Turnover refers to the rate at which employees depart from a company and are subsequently replaced by new hires, indicating the rotational movement of personnel within the organization.

Companies globally are intensifying their focus on workplace safety amid the challenging labor market, driven by increased turnover. The "Great Resignation" has heightened injury risks, particularly with new hires and returning employees. Employee injury rates typically follow a "bathtub curve," peaking in the first and final years of employment. Mid-career workers, traditionally the safest, are resigning at higher rates, posing long-term safety concerns. OSH Association statistics report that 40 percent of workers who are injured have been on the job less than a year (Duncan, 2022).

One of the short-term measures recommended is the introduction of psychological safety. With the Great Resignation leading to a potential return of employees, especially in high-risk environments, managing worker safety has become a critical challenge. Toxic work cultures have been a significant driver of turnover, emphasizing the importance of psychological safety. Workers who do not feel supported or safe are more likely to disengage and may face increased injury risks due to inadequate training and support. Conducting regular gap assessments with employee input can help identify and address immediate hazards, fostering a sense of involvement and support (Duncan, 2022).

2.4.2.3 Productivity and performance at work

Productivity, defined as the efficiency of output produced per person or system relative to the resources invested within a designated timeframe. It is typically assessed by the ratio of output to input, where a higher ratio signifies increased efficiency. While often used interchangeably, production and productivity have distinct meanings. Production refers to the total output of all employees at a specific moment (Maduok, 2015).

Performance, on the other hand, involves the effective coordination of employees' tasks across departments, contributing to overall organizational success. Various factors, including skills, training, motivation, and management policies, significantly influence employees' performance, impacting production, sales, profit, and market position. Management's understanding and efforts to develop and motivate employees are crucial for the company to excel and capitalize on market opportunities (Maduok, 2015).

2.4.2.4 Job satisfaction

Various researchers and practitioners have offered definitions of job satisfaction, with the most common descriptions being "a pleasurable emotional state resulting from the appraisal of one’s job as achieving or facilitating the achievement of one’s job values" and "the extent to which people like or dislike their jobs." Generally, job satisfaction contains employees' affective feelings towards their work, including specific aspects such as colleagues, pay, and working conditions. While enjoyment of individual tasks within a role moderately correlates with overall job satisfaction, other factors like meeting expectations also play a role (Hassard, Teoh and Cox, 2018).

Job satisfaction is a widely studied topic due to its significant impact on employees worldwide. The European perspective tends to focus less on traditional theories and more on workplace stress and the JDC model. Understanding job satisfaction is crucial for assessing its effects on worker health and productivity (Hassard, Teoh and Cox, 2018).

2.4.2.5 Compensations/Medical expenses

Workers' compensation insurance provides coverage for medical treatment necessary to recover the health and work capacity of injured workers. This includes expenses for hospital care, medication, transportation, and even psychotherapeutic support for the family, if deemed necessary by a physician. Additionally, the insurance ensures compensation for any temporary or permanent disability resulting from workplace accidents or occupational diseases (Coverflex, 2023).

2.4.2.6 Lost revenue

Lost revenue refers to the anticipated income that an organization projected to earn compared to the actual income it receives (SEFA, 2020).

2.5 Eye tracking

The primary tool utilized for tracking eye movements is commonly referred to as an eye tracker. This chapter provides an overview of various eye movement measurement techniques, with a focus on video-based trackers. The video-based trackers discussed here include both head-mounted and screen-based systems. Thus, eye tracking metrics and applications are also discussed in this chapter.

2.5.1 Techniques

Eye tracker techniques consist in four main categories: Electrooculogram (EOG), scleral contact lens/search coil, Photo-OculoGraphy (POG) or Video-OculoGraphy (VOG), and video-based combined pupil and corneal reflection (CR) (Duchowski, 2007b).

EOG records eye movements by measuring electric potential differences around the eye using electrodes. Scleral contact lens/search coil, precise method, utilizes a contact lens with a reference object. Early versions used a plaster ring, evolving to modern lenses with mounted stalks. While accurate, this technique, like with a wire coil, can be intrusive and uncomfortable (Duchowski, 2007b).

POG or VOG encompasses various techniques recording eye movements based on distinct eye features during rotation or translation. These methods, often utilizing infrared light, include measuring pupil shape, limbus position, and CRs. While not always offering point of regard measurement, they provide valuable ocular data, often requiring manual inspection due to limitations in automation and sampling rates (Duchowski, 2007b).

Video-Based Combined Pupil/CR trackers, often table/screen-mounted or head-worn, compute real-time point of regard using inexpensive cameras and image processing, capturing both the CR and pupil center. By measuring the first Purkinje image, they differentiate eye movements from head movements (Duchowski, 2007b). Formerly, precise head stabilization was necessary, especially with dual-Purkinje image trackers that separate translational and rotational eye movements (Duchowski, 2007b). However, the widespread adoption of video-based eye tracking has mitigated this need. Modern video-based eye trackers employ algorithms to identify key features in camera images: the pupil center and the CR center. While the pupil center shifts on the camera sensor with eye movement, the CR center remains relatively stationary, offering stability for measurements (see Figure 12) (SR Research, 2024).To compensate for head movements, trackers use the relationship between the pupil and CR positions, employing the pupil minus CR (p-CR) technique to address minor shifts between the eye tracker camera and the eye (Hooge, Holmqvist and Nyström, 2016).

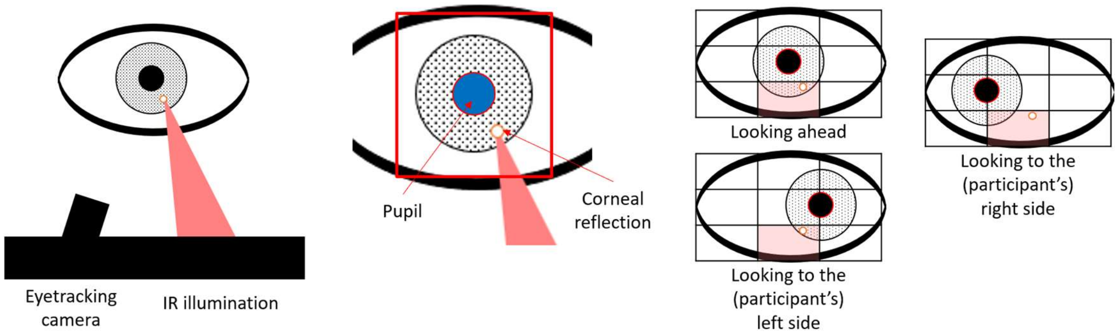

Figure 12 – Schematic representation of a table-mounted eye tracker operation: (1) Infrared light shines on the eye; (2) a close-up of the eye highlights the identified pupil; and (3) the tracking system determines gaze direction. These specifics occur when the head is stabilized. [Original image]

2.5.2 Software

In the standard eye tracking process, two main types of software are typically required: one for acquiring and recording data, and another for processing and analysing the collected data. Additionally, depending on the specific needs, developers may require dedicated software for different types of eye trackers (such as glasses or screen-based systems), particular eye tracking devices, or various stimulus types (like static or dynamic images). Notwithstanding, there are integrated software solutions available that encompass both data acquisition and analysis functionalities (Eyeware, 2022).

Regardless of the software utilized, it is important to consider several key features (Eyeware, 2022):

1. Accuracy
2. Calibration time
3. Optimal distance
4. Latency
5. Sampling rate
6. Tracking angles
7. Head movement range
8. Recovery time

2.5.3 Hardware

Currently, eye trackers are available in two main types: remote, which are screen-based, and mobile or wearable, like head-mounted devices such as glasses or virtual reality (VR) headsets (Eyeware, 2022). A comparing between screen-based and head-mounted eye trackers is presented in table 3, and diagrams for both types can be found in Figures 13 and 14.

Table 3 – Applications and limitations of screen-based and head-mounted eye trackers. Adapted from: Mento (2020).

Type of Eye Tracking System		Applications	Limitations
Screen-based	Non-head stabilized	- Psychology, neuroscience and vision experiments - Neuro compromised and infant participant populations - Assistive communication - Web ad software usability - Market Research for TV commercials, websites, advertisements - Gaming	- Participant must stay within range of the camera - Eye movements recorded on 1 plane - Excessive head movements can cause inaccuracy and dropped tracking - Will not work well in sunlight
	Head-stabilized	- High-fidelity experiments in neuroscience, physiology, vision or psychology - Experiments where sample rate and accuracy are more important than participant comfort	- Uncomfortable over long periods - Not very portable - Participants are not in a natural setting - Not possible for some participant populations
Head-mounted	Glasses	- Real-world human behaviour experiments - Sports training, kinesiology, rehabilitation, biomechanics, communication, human factors, ergonomics - Point of sale, store shelf marketing - Vehicles and high-fidelity simulators	- Data is relative to the field of view or screen video, not a fixed absolute coordination system - Statistical data requires more subjective analysis - More variability in results due to increased participant freedom - Eccentric eye movements not tracked as well
	Integrated	- Augmented reality - Virtual reality (VR) - Real-time devices like cameras - Medical analysis and eye surgical tools.	- Useful only with device in question - With VR, participant has to tolerate device - Often highly-specialized to a particular use-case

Screen-based eye tracking technology, prevalent in controlled research environments, involves participants positioned in front of a computer monitor or laptop, often equipped with a supplementary panel or standalone unit nearby. This setup facilitates the presentation of multimedia stimuli, including images, websites, videos, or games, which serve to elicit, record, and analyze eye movements. The insights gleaned from such data offer developers and researchers invaluable information about visual attention patterns (Eyeware, 2022). Noteworthy brands in this field include Tobii AB, headquartered in Danderyd, Sweden, renowned for its advanced eye tracking solutions. Another prominent player is iMotions A/S, based in Vesterbro, Denmark, known for its comprehensive eye tracking platform. These brands cater to a wide range of applications, spanning developmental psychology, neuroscience, clinical research, as well as tasks related to reading, language comprehension, production, and learning. The utilization of screen-based eye trackers extends beyond traditional research domains, providing insights into human behavior and cognition across various disciplines. Additionally, these eye trackers can be used with a head stabilizer to improve results.

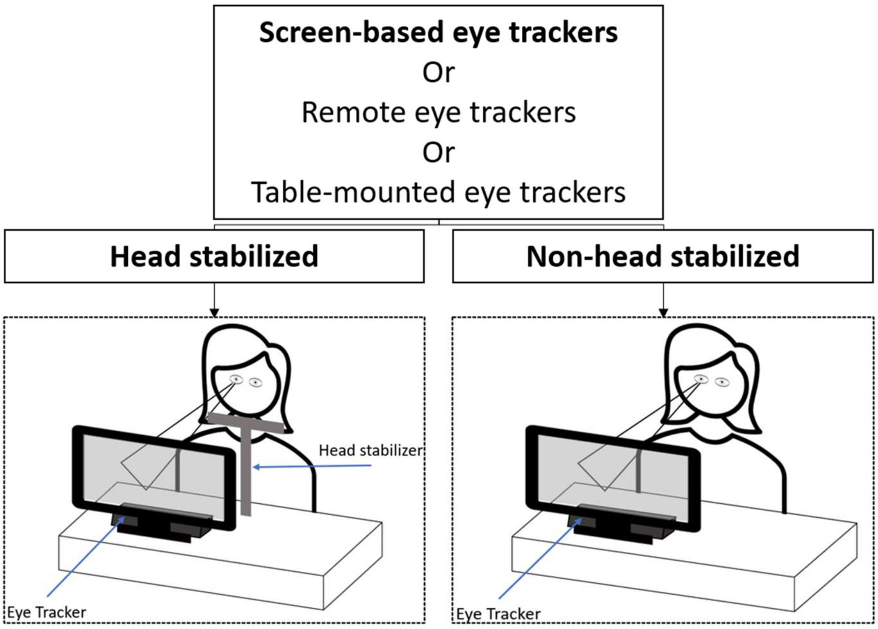

Figure 13 – Schematic of the two types of screen-based eye trackers [Original image].

Mobile eye tracking, also known as "head-mounted" eye tracking, involves participants wearing a device, commonly eye tracking glasses or a headband. Such systems usually incorporate a camera or mirror placed along the visual path of one or both eyes (monocular or binocular setup) and an extra camera to capture the scene or field of view (Mento, 2020).

Mobile eye tracking solutions, including eye tracking glasses and integrated or embedded systems such as VR headsets, offer portable options for studying behaviour in real-world settings, surpassing the spatial constraints of traditional stationary eye trackers. In VR environments, eye tracking enables users to interact with virtual elements simply by shifting their gaze, opening up possibilities for professional training, interactive entertainment, and assessing visual attention in retail settings. Combining eye tracking with head tracking yields comprehensive insights, with eye tracking focusing solely on eye movements and head tracking monitoring head motions. Together, they enhance user experiences, particularly in gaming applications. Overall, wearable eye tracking devices are ideal for experiments requiring naturalistic and dynamic responses from participants (Eyeware, 2022).

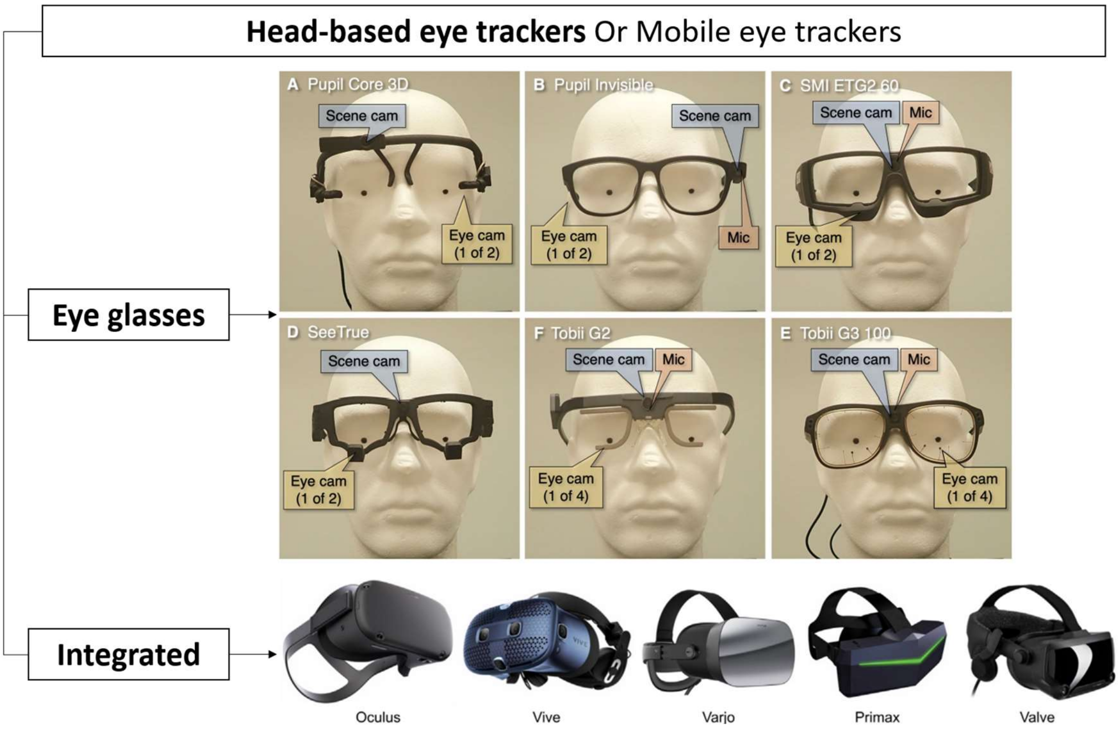

Figure 14 – Schematic of the two types of head-mounted eye trackers. Adapted from Garcia Fracaro et al. (2021) and Hooge et al. (2022).

2.5.4 Metrics

Eye tracking metrics categorize into four orders of data (Sharafi *et al.*, 2020). At the end of this subchapter, Figure 15 provides a schematic summary of the metrics discussed.

2.5.4.1 First order data

First-order data in eye tracking consist of unfiltered outputs including X and Y positions indicating gaze points, pupil diameter reflecting cognitive workload, and blink frequency linked to attention. These raw metrics require cleaning due to noise and outliers before analysis. Factors like ambient light, emotional states, and camera quality affect data quality. For instance, blink rates rise with stress but decline with intense focus. Detecting blinks may require advanced algorithms, and cleaning methods vary from visual inspection to statistical outlier removal (Sharafi *et al.*, 2020).

2.5.4.2 Second order data

Second-order data, like fixations and saccades, are derived from raw eye tracking outputs, using predefined thresholds. Eye tracking algorithms differentiate fixations from saccades based on spatial and temporal criteria, influencing data analysis outcomes. While voluntary fixations are of primary interest, involuntary ones, driven by reflexes, also occur, impacting tasks like software engineering (Sharafi *et al.*, 2020).

2.5.4.3 Third order data

Third-order data, extracted from fixations and saccades, includes metrics like fixation count, duration, and rates. These metrics reveal participants' attention distribution and task efficiency. For fair comparisons, metrics are adjusted by stimuli sizes. Saccade-related metrics, such as saccade count and duration, provide insights into task complexity and completion difficulty, with regression rates indicating the level of task challenge (Sharafi *et al.*, 2020).

To evaluate various fixation measurements, specific regions within a scene are designated as areas of interest (AOI). A heat map serves as a visual aid, depicting the distribution of fixations and gaze points. It utilizes varying shades of green, yellow, and red to indicate the concentration of gaze points within particular areas of the AOI (Eyeware, 2022).

2.5.4.4 Fourth order data

Fourth-order data includes scan paths, which depict eye gaze durations and lengths, indicating search efficiency. Algorithms like transition matrices and edit distance analyze scan paths, revealing viewing strategies. Metrics such as fixation spatial density and attention switching assess gaze dispersion and stimulus coverage. Linearity evaluates reading strategies. Cleaning data is crucial due to sensitivity to noise (Sharafi *et al.*, 2020).

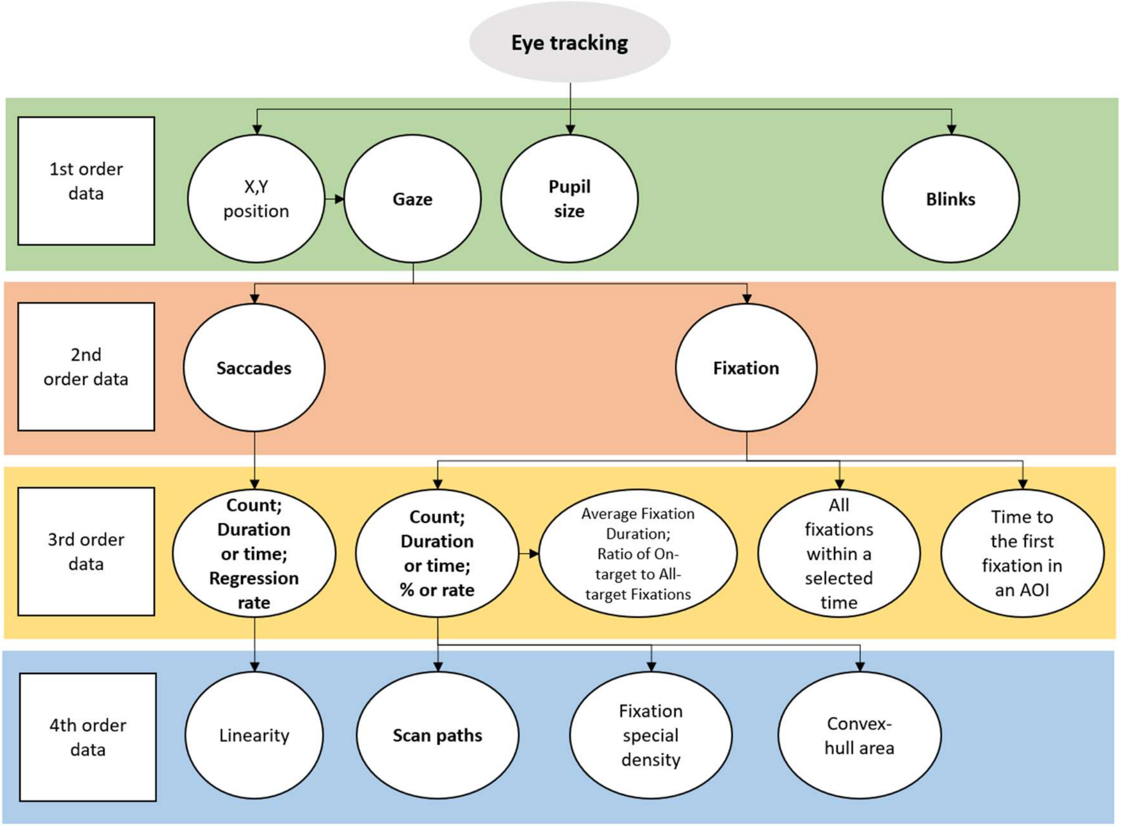

Figure 15 – Eye tracking data metrics scheme, based on Sharafi et al., (2020).

2.5.5 Applications

Eye tracking finds application in a wide array of fields, including neuroscience and psychology, where it contributes to attentional neuroscience, exploration of illusory contours, reading studies, and scene perception, encompassing areas like art and film. It also plays a role in visual search tasks, aiding in the development of computational models, and is employed in natural tasks and other information processing studies (Duchowski, 2007e). In industrial engineering and human factors, eye tracking is utilized in areas such as aviation, driving, and visual inspection (Duchowski, 2007c). Moreover, it holds significance in marketing and advertising, facilitating copy testing, evaluating print advertising and television enhancements, analyzing web pages, and optimizing product label designs (Duchowski, 2007d). Furthermore, eye tracking is valuable in computer science, supporting research in human-computer interaction and collaborative systems, as well as the development of gaze-contingent displays (Duchowski, 2007a).

Practical examples of how eye tracking is used in these different areas are:

- Neuroscience and Psychology: researchers may use eye tracking to examine how participants direct their gaze to different parts of a scene during reading or to investigate how optical illusions affect eye fixation patterns.
- Industrial Engineering and Human Factors: in aviation and driving, engineers may use eye tracking to study where pilots or drivers are looking during different phases of operation, helping to design safer and more intuitive interfaces.
- Marketing and Advertising: eye tracking is used to gain insights into consumer behavior and optimize advertising campaigns. For instance, marketing professionals may use eye tracking to assess the effectiveness of print or digital ads by monitoring where viewers' eyes are moving and how long they linger on different visual elements.
- Computer Science: user interface designers may use eye tracking to create displays that respond to the user's gaze, automatically adjusting content based on what is being viewed. This can be useful in games, augmented reality apps, and other forms of computer-human interaction.

Also, eye tracking can also be employed to monitor the mental and cognitive state of workers in various industries. By analyzing eye movement patterns, researchers and employers can gain insights into employees' cognitive processes, attentional focus, and emotional states while performing tasks. For example, in high-stress environments such as air traffic control or emergency response, eye tracking can help identify signs of fatigue, distraction, or cognitive overload, allowing for interventions to improve worker well-being and performance. Similarly, in office settings, eye tracking can assess employees' engagement levels during meetings, presentations, or training sessions, providing valuable feedback for optimizing workplace environments and fostering employee satisfaction and productivity.

3 State of the art

User Experience (UX) is a multifaceted concept that encompasses the overall interaction between individuals and the products, systems, or environments they engage with. UX originated in the field of human-computer interaction (HCI) and was primarily focused on the interaction between users and digital interfaces, such as websites, software applications, and VR environments. However, the concept has evolved to encompass a broader range of interactions beyond just digital interfaces. Today its principles are widely applicable across various domains, including the operation of industrial machines, for example. In this sense, UX extends beyond mere functionality to encompass aspects such as ease of use, efficiency, safety, and operator satisfaction. Designing for a positive UX, either in HCI or in industrial settings, involves understanding the needs, preferences, and behaviours of the user/operators, optimizing interfaces and controls for intuitive operation, and prioritizing user safety and well-being.

Physiological response measurement dimensions play a significant role in categorizing various UX techniques. There are four crucial dimensions that UX researchers must consider when incorporating projects (Romano Bergstrom *et al.*, 2014):

1. Subjective versus Objective
2. Real-Time versus Delayed
3. Natural Context versus Controlled Laboratory Environment
4. Invasive versus Non-invasive

UX research typically involves subjective and objective methods. Subjective measures, such as Likert scales, rely on users' self-reported ratings of satisfaction or task difficulty. However, these ratings may be biased due to memory limitations or social desirability biases, especially among older adults. Objective measures, on the other hand, include recording task completion time, errors, and physiological responses like skin conductance, or pupil dilation (Romano Bergstrom *et al.*, 2014).

Physiological measurements offer further insights into UX by objectively capturing emotional arousal. For instance, skin conductance can reveal implicit emotional responses to stimuli, even when users may not consciously recognize or report these feelings. Combining subjective ratings with physiological data provides a more comprehensive understanding of user reactions. For example, while subjective ratings may suggest minimal emotional response to an anti-tobacco advertisement, skin conductance data can uncover significant arousal levels, indicating deeper emotional engagement with certain elements of the ad (Romano Bergstrom *et al.*, 2014).

Integrating both subjective and physiological measures allows researchers to gain a nuanced understanding of UX, enhancing the accuracy and depth of insights gathered from UX studies (Romano Bergstrom *et al.*, 2014).

When studying psychological responses, researchers must decide whether real-time data collection is necessary or if post-task data suffices. Physiological measurements offer uninterrupted real-time feedback, such as using non-invasive devices like electrodermal activity (EDA) trackers or facial recognition software. These tools allow researchers to observe attention and emotion fluctuations as users interact within a scenario. Post-session follow-ups mitigate retrospective memory errors (Romano Bergstrom *et al.*, 2014).

Nevertheless, most of the reported research works traditionally occur in controlled laboratory environments, but as technology diversified and usage contexts expanded, studying users in natural settings became essential. Observing users in their own environments, such as homes or workplaces, provides insights into day-to-day challenges and needs that may go unnoticed in laboratory settings. Portable eye trackers facilitate studies outside labs, crucial for understanding real-world user behaviour, though some physiological measurement tools remain limited to laboratory use. Choosing between laboratory and natural settings depends on project goals; labs offer experimental control, while natural settings provide realistic contexts but risk external disruptions. Balancing these factors is crucial for effective UX research (Romano Bergstrom *et al.*, 2014).

When integrating biometrics into UX research, the invasiveness of the method is a key consideration. While some techniques like functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and magnetoencephalography (MEG) offer precise spatial and temporal resolution, they are often impractical for typical UX projects due to their invasive nature and resource requirements. Fortunately, electroencephalography (EEG), eye tracking devices and other non-invasive physiological measurement devices provide real-time monitoring of brain activity with excellent temporal precision, making them more practical and accessible for UX researchers. These tools offer a less intrusive and more cost-effective alternative to invasive techniques, making them suitable for studying user interactions with products in a variety of settings (Romano Bergstrom *et al.*, 2014).

Regarding the scales of objectiveness or subjectiveness (Figure 16A), real-time or delayed (Figure 16B), natural context or artificial laboratory (Figure 16C), and invasiveness (Figure 16D) in physiological response measurements, Figure 16 presents a comparison among satisfaction questionnaires, facial recognition, pupil dilation, EDA, and EEG.

Notwithstanding, addressing ethical considerations, it is crucial to respect user privacy and autonomy when collecting and analysing biometric data in UX research. Researchers must obtain informed consent, ensure data anonymity, and protect sensitive information from misuse or unauthorized access. Additionally, transparency about data collection practices and potential risks is essential to maintain trust with participants.

Given the aforementioned, the subsequent chapters will undertake an in-depth examination of both subjective and objective methods for analysing determinants of CFPW in the workplace environment.

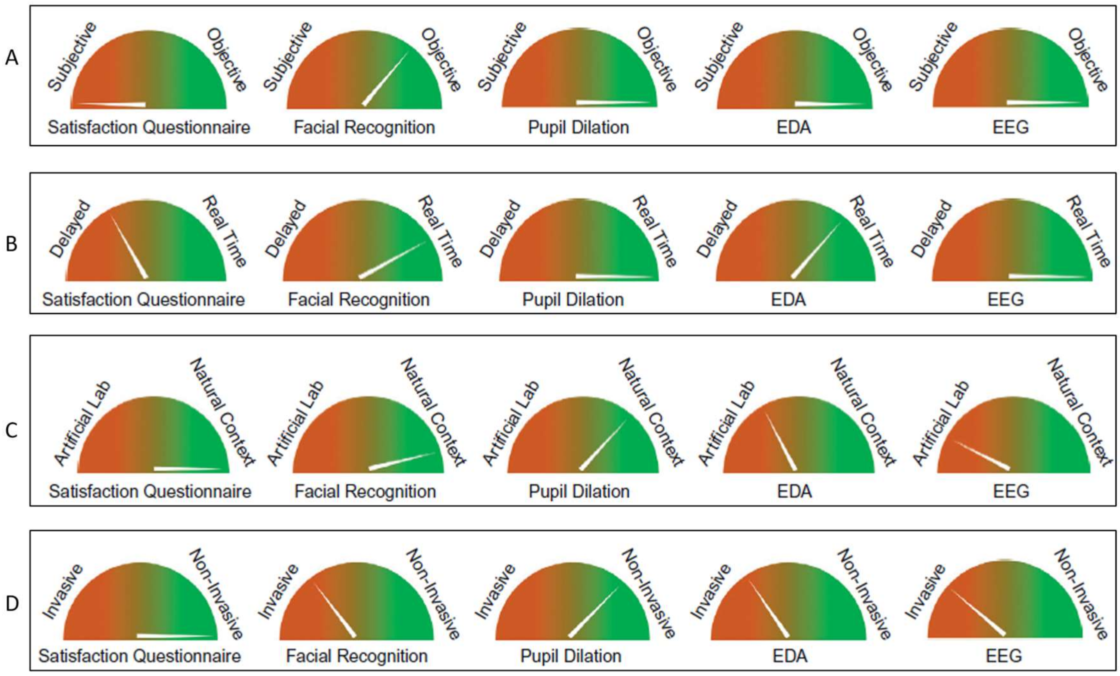

Figure 16 – Scales of Physiological Response Measurements: A – Objectiveness – The higher the objectivity of a measurement, the better; B – Real-Time – The more immediate the measurement, the better; C – Natural Context – Greater alignment with natural contexts enhances measurement quality; D – Invasiveness– Less invasiveness improves measurement quality. Adapted from: Romano Bergstrom et al. (2014).

3.1 Subjective methods for analysing determinants of cognitive function and psychological well-being

This chapter examines subjective methodologies for evaluating determinants of CFPW, encompassing diverse techniques such as questionnaires, interviews, self-assessment methods, and event reporting. Organized around distinct determinants like workload, occupational stress, fatigue, and attention, each section delves into numerous subjective methodologies.

The subsequent subjective techniques are assessed chronologically in each respective chapter, following their original development and publication sequence. This structure provides readers with insight into the progression of research in this field.

3.1.1 General

This chapter discusses methods applicable to multiple determinants of CFPW. A summary scheme can be found on Figure 17.

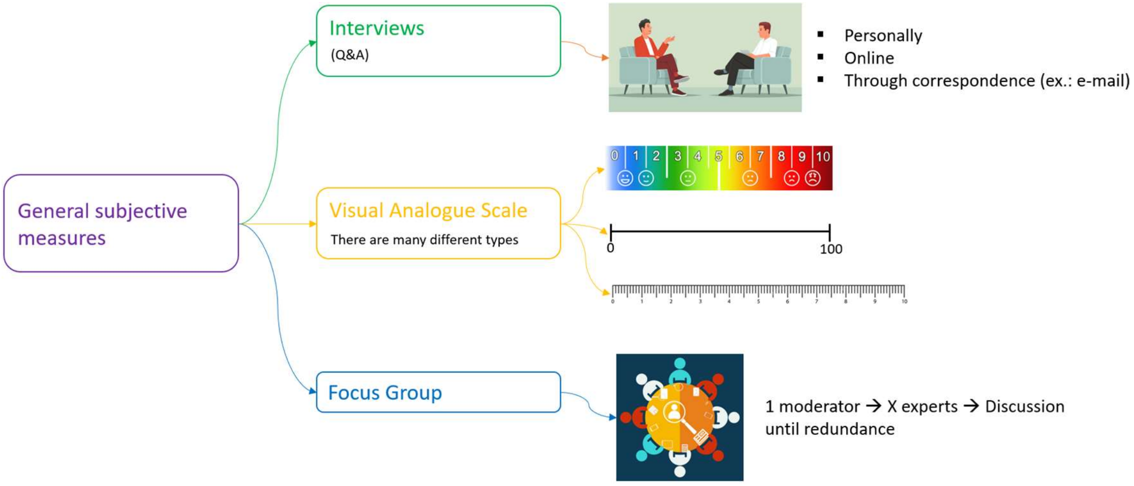

Figure 17 – General subjective measures visual presentation [Original image].

3.1.1.1 Interviews

Various interview formats exist, each serving distinct purposes. Structured interviews follow a predetermined order, akin to questionnaires but with direct interaction. Unstructured interviews foster open discussion, demanding adept management. Semi-structured interviews strike a balance, combining flexibility with a core question framework. Aligning interview questions with research objectives is crucial, with adaptability to participants' needs and fostering dialogue. Research methodologies, such as inductive and deductive approaches, shape question formulation. The length and quantity of interviews hinge on research context and practicalities, necessitating flexibility for adjustments (Rowley, 2012). Determinants of CFPW assessment through interviews requires tailored techniques for each determinant.

3.1.1.2 Visual Analogue Scale

The Visual Analogue Scale (VAS) is a single-dimensional numerical scale that utilizes a continuous line where participants can place a marker between 0 and 100% to denote their level of particular response (Lee and Kieckhefer, 1989). By doing so, the VAS converts measurement data from discrete response categories in a Likert scale into continuous and interval-level data (Ouwehand *et al.*, 2021).

VAS being an intensity scale can be employed to directly measure stress, workload, attention and fatigue in particular tasks.

3.1.1.3 Focus group

A focus group involves an informal conversation among chosen participants discussing particular topics. Typically comprising 6-8 individuals, participants collectively engage in a topic presented by the researcher. Led by a moderator, discussions are recorded and transcribed for qualitative analysis. Unlike individual interviews, focus groups emphasize group interaction, offering distinct insights. Comprehensive methodological literature guides the conduct of focus groups, addressing participant selection, moderation techniques, and data analysis approaches (Wilkinson, 1998).

Focus groups have been employed to explore determinants of CFPW within various domains, including occupational stress (Berland, Natvig and Gundersen, 2008), workload (Bos *et al.*, 2013), and fatigue (Scott *et al.*, 2010).

3.1.2 Workload

Subjective measures play a crucial role in workload assessment, involving operators describing their experienced workload during task performance, solely based on their subjective perceptions (Casner and Gore, 2010). These measures are essential for evaluating cognitive load in working memory and reflecting individual differences, as indicated by their correlation with physiological indicators such as HR variability (HRV) (Miller, 2001; Matthews, De Winter and Hancock, 2020). Despite their subjectivity, subjective measures are favoured for their ease of use and their impact on performance. However, challenges include the lack of continuous measurement and potential disruption of primary task performance if not timed properly, as well as the influence of contextual factors and familiarity on reliability (Miller, 2001; Matthews, De Winter and Hancock, 2020).

Two main techniques have emerged: numerical measurement, where operators assign numerical or ordinal values to their workload, and comparative measurement, where workload levels are compared between different task situations (Casner and Gore, 2010). Additionally, subjective measures can be classified into unidimensional and multidimensional scales, each differing in complexity and sensitivity. Recent research has validated the efficacy of unidimensional rating scales, once considered too simplistic, while being easier and less time-consuming to use and analyse. However, the predominant approach to workload assessment favours multidimensional methods, exemplified by widely used scales such as the NASA-Task Load Index (NASA-TLX) and the Subjective Workload Assessment Technique (SWAT), applicable in both real-world and simulated settings. Alongside these, various lesser-known scales complement workload assessment. Multidimensional scales offer a thorough analysis of workload facets, surpassing the capabilities of one-dimensional measures (Miller, 2001). In addition to these types of division, a visual scheme dividing workload scales into three types of workload assessments is presented in Figure 18.

The next step will involve exploring various scales to comprehensively understand and assess subjective workload measurement.

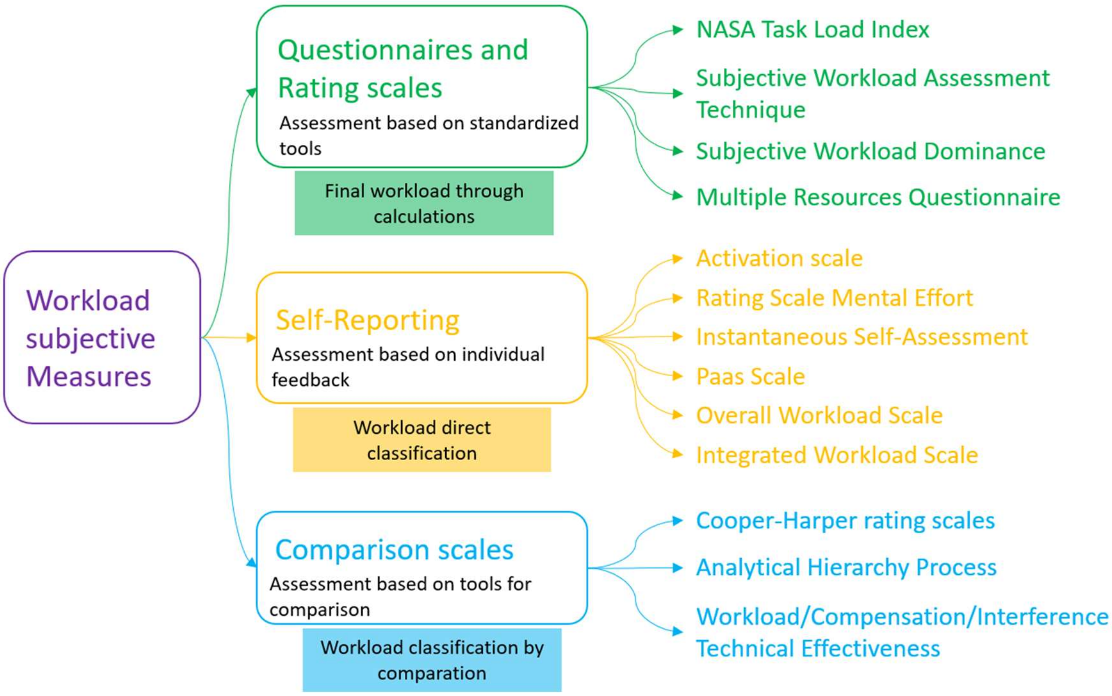

Figure 18 – Workload subjective measurement divided by assessment kind [Original image].

3.1.2.1 Activation scale

The Activation scale (Bartenwerfer, 1969), is a numerical technique used to measure workload. It ranges from 0 to 270 mm and involves assessing workload by measuring the distance in millimetres from the origin to the marked point. Reference points, such as "I am reading the newspaper," provide benchmarks for individuals to assess their workload relative to these tasks (Miller, 2001).

3.1.2.2 Cooper-Harper rating scales

The Cooper-Harper rating scale (Cooper and Harper, 1969), primarily utilized for assessing psychomotor workload in pilots, is a unidimensional numerical measure (Miller, 2001). Users navigate through a decision tree to derive a single score (Mitchell, 2019).

The Bedford Workload Scale, derived from the Cooper-Harper rating scale, assesses task completion feasibility, workload tolerability, and satisfaction without reduction (Miller, 2001). It functions as a unidimensional (Miller, 2001) numerical (Casner and Gore, 2010) numerical technique for workload evaluation. This instrument is also intended for assessing workloads in pilots; however, the modified Bedford workload scale is tailored specifically for instrument approach tasks. Unlike the TLX, which utilizes multiple sub-scales, the Bedford scale simplifies the process with a 10-element scale reminiscent of the Instantaneous Self-Assessment (ISA) technique. To address scale-loading issues, the Bedford scale includes detailed verbal descriptions for each of the 10 scale values, facilitating participant selection. Participants navigate a hierarchical decision tree to narrow down workload ratings, ensuring clarity. An advantage of the Bedford technique is its association of interpretations with each scale value, aiding in understanding. However, it can only be used post-task completion or when participants can focus on the scale display, limiting real-time application. Additionally, the scale's non-interval nature and the subjective interpretation of "spare capacity" pose challenges, potentially leading to varying interpretations among operators (Casner and Gore, 2010).

The Honeywell Cooper-Harper Rating scale, another variant of the original Cooper-Harper scale, serves as a numerical unidimensional adaptation designed for evaluating overall workload, rather than specifically targeting mental workload. It was initially crafted for assessing pilot workload (Miller, 2001).

Lastly, the Modified Cooper-Harper (MCH) scale is a 10-point unidimensional rating scale aimed at assessing overall workload. It extends the applicability beyond the original psychomotor scale, encompassing perceptual, cognitive, and communications workload. However, its validity and sensitivity remain contentious, with mixed findings on its effectiveness (Miller, 2001).

3.1.2.3 Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) (Saaty, 1980) offers a comprehensive approach to problem understanding, hierarchical structuring, and numerical evaluation. Emphasizing hierarchy in organizing complex systems, AHP utilizes pairwise comparison matrices, with values assigned based on relative importance, often through expert judgment (Eraslan, 2013). This multidimensional scale assesses workload using paired comparisons and eigenvector calculations. While AHP shows promise as a sensitive and reliable indicator of mental workload, data analysis can be complex (Miller, 2001).

3.1.2.4 Workload/Compensation/Interference/ Technical Effectiveness

The Workload/Compensation/Interference/ Technical Effectiveness (WCI/TE) scale is a numerical multidimensional matrix employed for subjective workload assessment. Its utilization entails intricate analysis to derive a score ranging from 0 to 100 (Miller, 2001). As many other workloads scales this instrument was initially created to assess workload on pilots (Casali, 1982).

3.1.2.5 Rating Scale Mental Effort

Akin to the Activation scale, the Rating Scale Mental Effort (RSME) (Zijlstra and Van Doorn, 1985) is a unidimensional numerical index utilized for measuring mental workload. It employs a continuous line spanning 150 mm, with markings at 10 mm intervals. Participants mark their perceived mental effort on this line, with nine anchor points indicating varying levels of effort. Mental effort is assessed by calculating the distance between the zero point and the individual's marked position on the scale (Miller, 2001; Alimohammadi *et al.*, 2019).

3.1.2.6 NASA Task Load Index Scale

The NASA-TLX (Hart, 1986) is a multidimension (Miller, 2001) numerical (Casner and Gore, 2010) technique designed to address the variability in workload perceptions. It utilizes six specific workload sub-scales, including Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration (Casner and Gore, 2010). Participants subjectively rate their workload along these sub-scales, either verbally or via other data collection devices such as paper and pencil or computer interfaces. The technique then combines these ratings to derive an overall workload measure, calculated through a ranking process that weights each sub-scale rating. This comprehensive approach accommodates different conceptualizations of workload and provides flexibility in data collection methods, allowing for real-time or post-task assessment (Casner and Gore, 2010).

The NASA TLX is recognized for its effectiveness in measuring mental workload, demonstrating sensitivity to workload changes and high diagnostic capability (Miller, 2001). However, its administration and analysis can be time-consuming, and consistency in ratings, particularly regarding the effort and frustration levels, has been questioned (Miller, 2001). Despite these drawbacks, the TLX remains a valuable tool for workload assessment, offering multidimensional insights into various aspects of workload experienced by operators during task performance.

A variant of the TLX scale, referred to as the NASA Raw Task Load Index (NASA-RTLX), calculates a score by summing the TLX test scores and dividing by six. This modified scoring approach for the NASA-TLX was found to produce results nearly identical to those of the original TLX scale. While the advantage lies in its simplicity and quick calculation, a notable disadvantage is its failure to consider the relative importance of each subscale (Miller, 2001).

3.1.2.7 Subjective Workload Assessment Technique

The SWAT (Reid and Nygren, 1988) utilizes a three-tiered approach—low, medium, and high—for each of the three dimensions: time load, mental load, and physiological stress load (Miller, 2001). The method scales these scores to create a unified rating system with interval properties. Initially, 27 cards representing all possible combinations of the three dimensions are ranked by participants to construct the scale. Subsequently, participants rate their workload, and these scores are then converted into a 0 to 100 scale based on the developed scale (Miller, 2001; Cain, 2007). While the SWAT scale aims to offer insights into human information processing resources, its efficacy has faced scrutiny. Some studies suggest its usefulness in estimating changes in mental workload, although concerns have been raised regarding its lack of subjective orthogonality. When compared to the NASA-TLX, the SWAT scale is generally perceived as inferior for measuring mental workload. However, some studies suggest that the SWAT scale may be more sensitive to changes in difficulty and context, potentially identifying cognitive mechanisms affecting mental workload. (Cain, 2007). While SWAT addresses concerns about subjective measures, its complex card-sorting procedure and scale development have been criticized for their time-consuming nature (Miller, 2001).

3.1.2.8 Subjective Workload Dominance

The Subjective Workload Dominance (SWORD) (Vidullch, Ward and Schueren, 1991) technique is a comparative unidimensional approach that evaluates workload across different tasks rather than assessing them independently. Operators rate task pairs using a 17-point scale, indicating relative workload. However, operator judgments may vary, so statistical analysis assesses consistency and reliability. Also, SWORD technique was originally made for pilots (Casner and Gore, 2010).

3.1.2.9 Instantaneous Self Assessment technique

The ISA scale (Jordan and Brennen, 1992), is a numerical (Casner and Gore, 2010) unidimensional (Miller, 2001) technique used to measure perceived workload. It employs five distinct ratings: excessive, high, comfortable, relaxed, and under-utilized (Miller, 2001). A straightforward method, ISA entails participants assessing their workload themselves during a task, typically at intervals of approximately two minutes, using a scale ranging from 1 (low) to 5 (high) (Jordan and Brennen, 1992). This method offers simplicity in data collection, requiring only basic materials like paper and pencil for the experimenter while observing and querying the operator during task execution (Casner and Gore, 2010). However, its effectiveness is hindered by the variability in individuals' perceptions of workload. Some may associate physical labour with high workload, while others may perceive mental or time pressure as indicative of high workload (Casner and Gore, 2010). Moreover, operators tend to use different portions and amounts of the 0 to 100 scale, leading to potential ceiling or floor effects and making standardization challenging (Casner and Gore, 2010). Despite these limitations, the ISA has shown comparability to other subjective workload measures, particularly the SWAT test (Miller, 2001). Thus, while the ISA provides a straightforward means for operators to express their workload perceptions, its reliability and standardization present ongoing challenges in workload assessment.

3.1.2.10 Paas scale

The Paas scale (Paas, 1992) is a 9-point Likert scale used to gauge the level of mental effort exerted in a task, ranging from 1 (very minimal mental effort) to 9 (very high mental effort) (Ouwehand *et al.*, 2021).

3.1.2.11 Overall Workload Scale

The Overall Workload Scale (OWS) is assessed by participants using a numerical unidimensional scale ranging from 0 to 100, where 0 signifies minimal workload and 100 indicates maximal workload. Each of the five degrees on the scale is represented by a single line. The OWS is quick and user-friendly, requiring minimal time for administration, preparation, and analysis. It is deemed nearly as effective as multidimensional scales and could serve as a valuable screening tool for identifying workload bottlenecks (Miller, 2001; Alimohammadi *et al.*, 2019).

3.1.2.12 Multiple Resources Questionnaire

The Multiple Resources Questionnaire (MRQ) is a simple 17-item tool used to assess subjective workload. It expands upon Multiple Resource Theory, informed by studies on lateralized processes, to pinpoint specific resource burdens, ensuring high diagnostic capability (Boles and Adair, 2001). While the superiority of MRQ as a workload assessment tool remains uncertain, integrating it with hierarchical measures like the MCH scale could offer analysts a practical, validated workload measurement tool with diagnostic capabilities (Cain, 2007). The MRQ offers a straightforward subjective workload evaluation rooted in the consideration of various resources (Boles and Adair, 2001).

3.1.2.13 Integrated Workload Scale

The Integrated Workload Scale (IWS) (Pickup *et al.*, 2005) is an alternative approach to evaluating mental workload. It consists of a single-dimensional scale featuring nine distinct levels, each accompanied by a title, brief explanation, and uniquely assigned colour. Initially applied in train signalling units, it now serves to gauge the peak and minimum mental workload encountered by individuals within specific timeframes and scenarios (Alimohammadi *et al.*, 2019).

3.1.2.14 Other rating scales

Numerous alternative techniques are available for assessing mental workload, such as the Defense Research Agency Workload Scale[1], Information Processing/Perceptual Control Theory[2], Malvern Capacity Estimate[3], Prediction of Operator Performance[2], Pro-SWAT[4], Quantitative Workload Inventory[5], VACP[6] (Visual, Auditory, Cognitive, Psychomotor method) and Driver Activity Load Index[7]. However, these methods will not be covered in this chapter. Interested readers are advised to consult the provided references for additional information on these methodologies.

It is crucial to acknowledge the potential existence of further subjective techniques, including those tailored for specific studies and others yet to undergo validation. However, these additional techniques have not been discussed or referenced in this context.

3.1.2.15 Conclusions

Subjective workload assessment is common, yet it poses inherent challenges. Many rating scales initially designed for aviation pilots have been adapted for broader application across various groups. Table 4 provides a concise overview of the presented scales.

Comparative scales like SWORD and AHP enable the comparison of distinct tasks, though validating these methods poses challenges, particularly when equating dissimilar tasks. Despite their practical applicability, analysing data derived from these scales can be intricate, with additional complexities arising from ensuring operator consistency (Miller, 2001; Casner and Gore, 2010). Moreover, numerical scales, commonly Likert-based, are prevalent in workload assessment. While unidimensional scales are typically deemed more practical, the widely accepted NASA-TLX scale is multidimensional. However, interpretation and validity of rating scales vary, and analysing subjective data faces manipulation and interpretation issues.

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[1] Farmer, E.W., Belyavin, A.J., et al. (1995). Predictive Workload Assessment: Final Report. Farnborough, Hampshire, Defence Research Agency

[2] Hendy, K.C. and Farrell, P.S.E. (1997). Implementing a model of human information processing in a task network simulation environment. Toronto, Defence and Civil Institute of Environmental Medicine: 110

[3] Goillau, P. J., & Kelly, C. J. (2017). Malvern Capacity Estimate (MACE)-a proposed cognitive measure for complex systems. In Engineering Psychology and Cognitive Ergonomics (pp. 219-225). Routledge.

[4] Kuperman, G. G. (1985). Pro-Swat Applied to Advanced Helicopter Crewstation Concepts. Proceedings of the Human Factors Society Annual Meeting, 29(4), 398-402.

[5] Spector, P. E., & Jex, S. M. (1998). Development of four self-report measures of job stressors and strain: interpersonal conflict at work scale, organizational constraints scale, quantitative workload inventory, and physical symptoms inventory. Journal of occupational health psychology, 3(4), 356.

[6] Aldrich, T.B. and McCracken, J.H. (1984). A computer analysis to predict crew workload during LHX ScoutAttack Missions Vol. 1. Fort Rucker, Alabama, US Army Research Institute Field Unit, Fort Rucker, Alabama.

[7] Pauzié, A. (2008). A method to assess the driver mental workload: The driving activity load index (DALI). IET Intelligent Transport Systems, 2(4), 315-322.

Although scales like SWAT may offer sensitivity, others like NASA-TLX boast higher user acceptance. Less rigorous but quicker alternatives, such as VAS, are explored, yet standardizing scale development remains a challenge. Method preference depends on both scale type and the specific aim of the study.

Table 4 – Overview of the classification of workload assessment scales.

	Unidimensional	Multidimensional	Numerical	Comparative
Activation scale	x		x	
Cooper-Harper	x		x	
MCH	x		x	
Bedford	x		x	
AHP		x		x
WCI/TE		x	x	
RSME	x		x	
NASA-TLX		x	x	
SWAT		x	x	
SWORD	x			x
ISA	x		x	
Paas scale	x		x	
MRQ		x	x	
OWS	x		x	
IWS	x		x	

To better visualize the timeline, Appendix 1, shows the chronological distribution of various workload scales.

3.1.3 Occupational stress

Assessment of work-related stress often involves utilizing subjective questionnaires. However, this method can only gather information about the user's current stress level. Questionnaire-based subjective measurement requires active participation from the user to ensure an accurate assessment of stress levels and avoid potential misinterpretation (Hashmi and Yadav, 2018).

3.1.3.1 Perceived Stress Scale

A more accurate assessment of individual stress levels can be accomplished using various specialized tools, among which is the Perceived Stress Scale (PSS) (Cohen, Kamarck and Mermelstein, 1983). Developed initially in 1983, the PSS continues to be widely utilized for evaluating how different circumstances affect individuals' perceived stress levels. It consists of inquiries pertaining to emotions and thoughts over the preceding month, with respondents indicating the frequency of their experiences. It is crucial to treat each question as distinct and respond promptly without excessive deliberation. Calculating the PSS score involves reversing scores for specific questions and then totalling the scores for each item. PSS scores can range from 0 to 40, with higher scores indicative of greater perceived stress levels. The significance of the PSS lies in recognizing the primacy of individuals' perceptions of their life events. Even if two individuals undergo identical experiences, their perceptions of stress may vary, resulting in divergent categorizations based on their total scores. However, it is important to note that this scale is not suitable for assessing specific tasks.

3.1.3.2 Depression Anxiety and Stress Scale

The Depression Anxiety and Stress Scale (DASS) (P. F. Lovibond and Lovibond, 1995) had originally 42 items, being then shortened to the DASS-21 to reduce administration time. It is widely used, having good reliability and validity reported across cultures (Oei *et al.*, 2013). The structure of the DASS-21 consists of three subscales: Depression, Anxiety, and Stress, each containing 7 items assessing the psychological states related to these constructs (Oei *et al.*, 2013).

3.1.3.3 Maslach Burnout Inventory™

The MBI-General Survey (MBI-GS) (Schaufeli *et al.*, 1996) was developed for application across occupational sectors beyond human services and education, encompassing roles such as customer service, maintenance, manufacturing, management, and various other professions. A modified version of the MBI-GS, known as the MBI-GS (S), has been tailored to assess burnout among college and university students (Maslach *et al.*, 2024).

The MBI-GS encompasses three dimensions (Maslach *et al.*, 2024):

1. Exhaustion evaluates feelings of being overwhelmed and drained by one's job.
2. Cynicism assesses a sense of detachment or indifference towards one's work.
3. Professional Efficacy gauges satisfaction with past and present achievements, while also examining an individual's belief in their ability to continue performing effectively in their role.

The MBI-GS scale does not directly measure stress; rather, it focuses on assessing its specific effect, burnout.

3.1.3.4 Lipp's stress symptoms inventory

Assessment of stress levels can be performed using Lipp's stress symptoms inventory (LSSI) for adults. This tool enables the identification of symptoms exhibited by individuals, evaluates whether they meet the criteria for a stress diagnosis, and discerns the primary symptoms (whether physical or psychological) as well as the stage of the stress process. The LSSI is a validated questionnaire consisting of structured inquiries and is widely employed in various national surveys. This instrument is self-administered (Molina *et al.*, 2012; Leovigildo, David and Mendes, 2016). Akin to the PSS, this tool is not suitable for assessing stress related to specific tasks.

3.1.3.5 Relative Stress Scale

The Relative Stress Scale (RSS) assesses occupational stress, normed on dementia caregivers. Widely utilized in clinical and research settings, it examines various stress dimensions effectively (Lesher, 2015). The RSS highlights three categories: "emotional distress," "social challenges," and "negative emotions."(Hashmi and Yadav, 2018).

3.1.3.6 Perceived Occupational Stress

The Perceived Occupational Stress (POS) scale, developed by Marcatto et al. (2022), is a new and compact instrument crafted to evaluate an individual's personal perception of stress encountered in the workplace. However, due to its recent introduction in research, there is a lack of cross-cultural studies examining the suitability and accuracy of this assessment tool (Yıldırım *et al.*, 2024).

The POS scale was developed as a concise tool specifically for evaluating occupational stress, aiming to minimize the burden on workers during assessment. By incorporating multiple items, it meets essential psychometric standards, focusing on work-related stress perceptions to avoid confusion with non-occupational stress. Through a pragmatic approach, it encompasses widely accepted concepts of work-related stress, addressing its fundamental components and enhancing measurement accuracy while being efficient for workers (Yıldırım *et al.*, 2024).

3.1.3.7 Conclusions

The majority of the methods discussed ca not be used to evaluate stress related to tasks, with the VAS being the most effective. Additionally, it is important to acknowledge the possibility of other scales not covered here due to their limited recognition in the literature.

3.1.4 Attention

When it comes to evaluating attention, objective assessments are typically more advisable (Fuermaier *et al.*, 2021). Nonetheless, subjective methods, such as direct observation of the participant or worker by the researcher or responsible individual, can also be utilized. It is worth noting that during the literature review, only two scales were identified, and neither of them is suitable for specific task evaluation.

3.1.4.1 Attention and Performance Self-Assessment

Attention and Performance Self-Assessment is utilized to evaluate and analyse the everyday memory and concentration abilities of individuals with varying degrees of subclinical or clinically significant underlying conditions. This questionnaire comprises a total of 21 items, with the results available in two formats: a composite score (APS-20) or two subscale scores consisting of nine items each, namely "Prospective memory performance" (AP-F1) and "Difficulty in maintaining focused attention performance" (AP-F2) (Bankstahl and Görtelmeyer, 2014). This scale is available for purchase.

3.1.4.2 Subjective Attention Scale

The Subjective Attention Scale comprises fifteen statements, with three statements corresponding to each of the five types of attention outlined by Sohlberg and Mateer (1989): focused, sustained, selective, alternating, and divided. Within each set of three statements, one is reverse scored. Participants were instructed in the preamble to the scale to rate the extent to which they agreed with each statement, indicating how well it described them generally, rather than at the time of testing, on a 1-5 scale ranging from Strongly Disagree to Strongly Agree. Scores across all questions were totalled to generate a score ranging from 15 to 75, with higher scores reflecting a more positive subjective evaluation of attention (Welsh, 2020). This scale has not undergone validation outside of the original study.

3.1.5 Fatigue

Subjective fatigue assessment tools, such as self-administered questionnaires, gauge individuals' perceptions of fatigue consequences or intensity. These questionnaires, typically quick to complete, aid in minimizing work disruption. The variety of fatigue questionnaires reflects the evolving understanding and management needs across various fields, given the elusive nature of fatigue (Techera *et al.*, 2016).

3.1.5.1 Fatigue Severity Scale

The fatigue severity scale (FSS) (Krupp, 1989) is a widely employed nine-item self-report questionnaire used to assess fatigue levels. Respondents rate each item on a scale of one to seven, with higher scores indicating greater fatigue severity. Unlike measuring symptom intensity, the FSS focuses on evaluating how fatigue impacts functioning and behavioural aspects rather than solely the intensity of fatigue symptoms (Shahid, Shen and Shapiro, 2010). The results of FSS evaluations reveal the extent of limitations caused by fatigue in daily function and behaviour, and the scale has been shown to differentiate among groups with varying degrees of fatigue. Additionally, preliminary evidence suggests that the FSS can predict longitudinal changes in individual fatigue levels. (Techera *et al.*, 2016) It is not designed to be used as a task-specific questionnaire.

3.1.5.2 Fatigue subscale of the Visual Analogue Scale

The VAS of Fatigue (VAS-F) (Lee, Hicks and Nino-Murcia, 1991) comprises 18 items, with 5 focusing on measuring an individual's energy levels and the remaining 13 assessing subjective feelings of lassitude. Unlike other questionnaires, the VAS-F does not utilize numerical scales or ratings to evaluate fatigue; instead, it presents participants with a continuous 100 mm line for each item. At one end of the line, there is a descriptor such as "not at all tired," while at the opposite end, it reads "extremely tired." Participants are instructed to mark a cross along the line to indicate their level of fatigue. While this approach makes administering the VAS-F simple and straightforward, it can be challenging to interpret quantitatively (Techera *et al.*, 2016) e (Shahid, Shen and Shapiro, 2010). The VAS-F can discern fatigue levels, as seen in pre- and post-sleep deprivation scores (Techera *et al.*, 2016).

3.1.5.3 Need for Recovery Scale

The Need for Recovery Scale (NRS) (Macnab *et al.*, 1991) is a single-dimensional scale crafted to assess fatigue's immediate impact post-workday (van Veldhoven, 2003). It comprises 11 items rated on a binary, yes-no, scale, later converted to a 100-point scale, reflecting the individual's overall fatigue score (Techera *et al.*, 2016).Its applicability is not limited to a questionnaire tailored for a specific task.

3.1.5.4 Chalder Fatigue Scale

The Chadler Fatigue (CF) Scale was initially developed in 1993 with 14 items to measure perceived fatigue (Chalder *et al.*, 1993). Its reliability makes it suitable for assessing symptom severity, especially in epidemiological studies. However, it is recommended to complement its use with other measures in clinical settings (Shahid, Shen and Shapiro, 2010).

In contrast, the CF-11, a revised version published in 2010 (Cella and Chalder, 2010), comprises 11 items assessing physical and mental fatigue symptoms. It offers two rating methods: bimodal scori(Braga *et al.*, 2020) Likert scoring (0–3) (Braga *et al.*, 2020). Scores range differently depending on the subscale and scoring system used. Despite its efficacy in distinguishing between physical and mental fatigue, it lacks specific scores for varying fatigue severity levels. Scores range from 0–7 for CF-PF, 0–21 for CF-MF, and 0–11 or 0–33 for CF-total, depending on the scoring system. Lower scores indicate lower fatigue levels. In epidemiological studies, individuals with a total score ≥ 4 are identified as severely fatigued under bimodal scoring (Adın *et al.*, 2022). Its intended use does not involve tailoring it for specific tasks.

3.1.5.5 Checklist Individual Strength

The Checklist Individual Strength (CIS) evaluates workers' fatigue across four dimensions: subjective experience, concentration, motivation, and physical activity (Shahid, Shen and Shapiro, 2010; Sagherian and Geiger Brown, 2016; Techera *et al.*, 2016). Administered with a Likert scale, it yields reliable scores and effectively discriminates between fatigue levels (Shahid, Shen and Shapiro, 2010; Sagherian and Geiger Brown, 2016; Techera *et al.*, 2016). CIS, developed by Vercoulen et al. (1994), measures subjective and psychological fatigue aspects, comprising 20 items (Sagherian and Geiger Brown, 2016; Techera *et al.*, 2016; Braga *et al.*, 2020). It employs a 7-point Likert scale, with a cutoff of 36 points for fatigue measurement. Scores range from 20 to 140 points, with higher scores indicating greater fatigue intensity. After scoring, certain items are reversed for accurate assessment (Braga *et al.*, 2020) Respondents reflect on their experiences over the past two weeks, generating four distinct scores for fatigue severity, concentration, motivation, and physical activity (Sagherian and Geiger Brown, 2016). CIS's benefits extend to its ability to discern fatigue levels across various populations over different time frames (Braga *et al.*, 2020) The CIS is a multidimensional instrument measuring chronic fatigue (Sagherian and Geiger Brown, 2016; Braga *et al.*, 2020). It cannot be applied as a task-specific questionnaire.

3.1.5.6 Multidimensional Fatigue Inventory-20

The Multidimensional Fatigue Inventory-20 (MFI-20) (Smets *et al.*, 1995) is a questionnaire consisting of 20 items categorized into five dimensions: general fatigue, physical fatigue, mental fatigue, reduced motivation, and reduced activity (Shahid, Shen and Shapiro, 2010; Techera *et al.*, 2016). Each dimension comprises four items rated on a 5-point Likert scale. Scores within each dimension range from 4 to 20, with higher scores indicating elevated fatigue levels (Techera *et al.*, 2016). Initially, this questionnaire underwent testing among healthy volunteers, including students, physicians, and army recruits (Techera *et al.*, 2016), later being broadly used in cancer patients (Shahid, Shen and Shapiro, 2010). This questionnaire is not intended for assessing task-specific fatigue.

3.1.5.7 Swedish Occupational Fatigue Inventory

The Swedish Occupational Fatigue Inventory (SOFI) (Åhsberg, Garnberale and Kjellberg, 1997) is a tool designed to assess individuals' perceived fatigue in the workplace (Sagherian and Geiger Brown, 2016). It offers a comprehensive evaluation of fatigue perception, considering various aspects of work-related tasks. Developed by Åhsberg (2000), the latest version of SOFI emphasizes subjective fatigue assessment within an occupational context. By employing verbal expressions evaluated on a numerical scale, SOFI provides valuable insights into the subjective experience of fatigue in the workplace, contributing to a better understanding of the impact of fatigue on individuals' work performance and well-being (Sagherian and Geiger Brown, 2016). SOFI-20 comprises 20 items that delve into different dimensions of fatigue, including lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness (Techera *et al.*, 2016). These items are rated on a 7-point scale, allowing respondents to indicate the extent of their experience with each fatigue-related symptom, ranging from "not at all" to "to a very high degree." The recall period for assessing fatigue levels can vary depending on the study's purpose, allowing for flexibility in data collection (Sagherian and Geiger Brown, 2016). It is not suitable for use as a questionnaire specific to tasks.

3.1.5.8 Fatigue Assessment Scale

he Fatigue Assessment Scale (FAS) (Michielsen, De Vries and Van Heck, 2003) comprises 10 items sourced from existing fatigue measures, with half devoted to assessing physical fatigue and the remaining half focused on evaluating mental fatigue (Techera *et al.*, 2016). These items, selected from various sources such as the Energy and Fatigue subscale of the World Health Organization Quality of Life Assessment questionnaire, the CIS, and the CF, encompass both physical and mental fatigue aspects. An additional item, "mentally I feel exhausted," was incorporated into the scale. Unlike some other fatigue scales, the FAS does not differentiate between physical and mental fatigue states but rather treats them as components of a unified fatigue construct (Sagherian and Geiger Brown, 2016).

Respondents rate their experiences using a 5-point Likert scale, ranging from "Never" to "Always," without a specified timeframe for recall (Michielsen, De Vries and Van Heck, 2003). Developed two decades ago, the FAS has found utility across diverse occupational groups, including military aviation shift workers, pilots, and nurses, as well as in patient populations such as those with sarcoidosis, stroke, and cancer (Sagherian and Geiger Brown, 2016). Its utility does not extend to being a questionnaire customized for individual tasks.

3.1.5.9 Occupational Fatigue Exhaustion Recovery Scale

The Occupational Fatigue Exhaustion Recovery scale (OFER) (Winwood, Lushington and Winefield, 2006) questionnaire serves the purpose of assessing both acute and chronic fatigue, as well as inter shift recovery. Thus, it comprises three subscales: acute fatigue, chronic fatigue, and inter shift recovery, each containing five items. While the specific dimensionality of fatigue is not explicitly stated, each subscale is understood to represent a distinct dimension or aspect of fatigue. The conceptualization of fatigue and the significance of recovery are grounded in the allostatic load theory, which elucidates the neurophysiological responses to external stressors, particularly in work settings. With a total of 15 items, respondents rate their agreement on a 7-

point Likert scale, ranging from strongly disagree to strongly agree. The recall period for items spans the last few months, providing a retrospective view of fatigue experiences. Since its publication in 2006, the OFER-15 has seen frequent use within healthcare working populations (Sagherian and Geiger Brown, 2016).

3.1.5.10 Other rating scales

Numerous fatigue scales exist, designed for assessing either occupational fatigue or fatigue in patients. However, some of these scales, such as Bipolar Fatigue Assessment Questionnaire, Yoshitake Fatigue Assessment Questionnaire (Braga *et al.*, 2020), Functional Assessment of Cancer Therapy, Brief Fatigue Scale, Fatigue Symptom Inventory and Piper Fatigue Scale (Shahid, Shen and Shapiro, 2010) have not been mentioned here and will not be further utilized or evaluated.

3.1.5.11 Conclusions

The tools presented offer valuable insights into fatigue, whether approached as a singular aspect or from multiple dimensions. Typically concise, with item counts ranging from 10 to 20, they are user-friendly and place minimal burden on both respondents and administrators. Psychometric research conducted among working populations attests to their reliability and validity (Sagherian and Geiger Brown, 2016; Techera *et al.*, 2016). Among them, the CIS, FAS, NRS, OFER, SOFI, and VAS-F hold promise in serving as surveillance instruments for monitoring employee fatigue and enhancing workplace safety. However, when it comes to task-specific fatigue assessment, especially in laboratory settings, the VAS-F or a single VAS emerges as the sole subjective measure available. The selection of an appropriate measure or combination thereof depends on how the researcher defines and operationalizes fatigue, as well as the specific objectives of the study.

3.1.6 Others

The next two scales should be address when considering determinants of CFPW.

3.1.6.1 Brief Coping Orientation to Problems Experienced

The Brief Coping Orientation to Problems Experienced (COPE) (Carver, 1997) is a condensed version of the COPE inventory (Carver, Scheier and Weintraub, 1989), incorporating Lazarus', Carver and Scheier's theories related to stress (Hanfstingl *et al.*, 2023). It categorizes coping into problem-focused, emotion-focused, and less effective strategies. Developed due to length concerns, it comprises 14 scales with two items each (Carver, 1997): acceptance, active coping, behavioural disengagement, denial, emotional support, humour, instrumental support, planning, positive reframing, religion, self-blame, self-distraction, substance use, and venting (Hanfstingl *et al.*, 2023).

3.1.6.2 Penn State Worry Questionnaire

The Penn State Worry Questionnaire (PSWQ) (Meyer *et al.*, 1990) is a 16-item instrument to measure the trait of worry. Worry involves repetitive negative thinking about uncertain future events, often driven by cognitive avoidance to prepare for potential threats, intensifying stress-related responses (Anniko, Boersma and Tillfors, 2019).

3.2 Objective methods for analysing determinants of cognitive function and psychological well-being

When an individual undergoes an emotion, various internal bodily functions such as HR, skin conductance, blood pressure (BP), brain signals, among others, are impacted, and/or observable physical changes in facial expression, voice, or behaviour may occur. These physiological and physical reactions, along with additional contextual information, offer a reliable method for objectively assessing determinants of CFPW (Goyal *et al.*, 2016).

Once the decision to employ biometrics has been made, it becomes crucial to meticulously assess the available options. Each method generates different data, so depending on the desired information, one may choose to utilize one or more of the following methods (Romano Bergstrom *et al.*, 2014).

Two crucial factors that must be taken into account when considering the integration of biometrics into a study are: (1) the project's budget and (2) the available time. The decision to purchase a new device, invest in learning a new methodology, handle more extensive and intricate data analyses, potentially requiring additional researchers' assistance, all necessitates thorough deliberation. Is the endeavour justified by the outcomes? What specific results are required, and to what extent is detailed information important? It is probable that new devices will become more cost-effective in the near future, and the data evaluation process will become progressively simpler and more streamlined—mirroring the trend already observed with eye-tracking techniques. However, akin to eye tracking, the research objectives must be carefully assessed before determining the necessity of incorporating biometrics (Romano Bergstrom *et al.*, 2014).

The upcoming chapters will present various objective methods for assessing determinants of CFPW. Each method will be introduced with a brief definition, followed by an explanation of how the determinants of CFPW influences the objective measure. Figure 19 shows examples of objective measures sources in the human body.

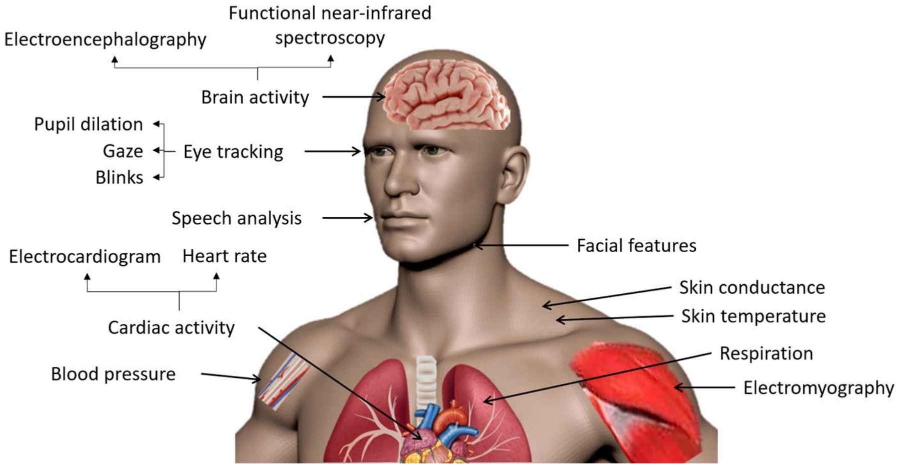

Figure 19 – A 3D model of the human body highlighting locations for gathering various physiological data [Original image].

3.2.1 Eye tracking

This chapter will prioritize first-order eye tracking data, as it serves as the foundation for deriving other metrics.

3.2.1.1 Pupil dilation

Pupillometry, a method measuring pupil diameter changes, offers insights into brain activity beyond light responses. It captures involuntary cognitive and emotional fluctuations, unaffected by biases like social desirability. However, interpreting these changes requires contextual understanding (Romano Bergstrom *et al.*, 2014).

Various studies show that pupil diameter increases with higher mental workload (Miller, 2001). Alternatively, pupil dilation diminishes over time as fatigue increases (Hopstaken *et al.*, 2015; Bafna and Hansen, 2021). Pupil dilation metrics, like dilation rate, are effective for assessing attention (Zhao *et al.*, 2019), with pupils dilating more with increased attention and contracting with reduced attention, (Kang, Huffer and Wheatley, 2014). In stress detection, average pupil diameter serves as a widely used indicator, with stress levels correlating with higher mean pupil diameters (Sharma and Gedeon, 2012).

3.2.1.2 Gaze

Gaze, the direction of one's visual focus, serves as a vital indicator of attention and mental states during social interactions. Prolonged fixation on a screen object and frequent focus shifts reflect varying stress levels (Sharma and Gedeon, 2012). Peak fixation duration inversely correlates with mental workload, while saccade parameters may show mixed associations(Volden, De Alwis Edirisinghe and Fostervold, 2019). Fatigue reduces fixation time and increases average duration, with decreased saccade distance (Zhao *et al.*, 2023). Gaze direction indicates attention focus, with gaze patterns revealing objects of interest (KAWAI, 2011; Yucel *et al.*, 2013). Finally, eye gaze correlates with stress levels (Hashmi and Yadav, 2018).

3.2.1.3 Blinks

Blink frequency serves as a multifaceted indicator influenced by stress and workload contexts. Conflicting findings regarding stress and blink frequency highlight contextual nuances (Sharma and Gedeon, 2012). While predominantly utilized to gauge visual workload, it also reflects mental workload and can vary due to environmental factors such as lighting changes (Miller, 2001). Blink rate variability aligns with attentional shifts during tasks, indicating the significance of presented stimuli and offering an objective measure for attention monitoring (Maffei and Angrilli, 2019). Real-world driving experiments demonstrate a positive correlation between heightened stress levels and increased blink frequency, while computer-based tasks may show the opposite trend. Additionally, rapid eye closure has been suggested as a stress indicator (Sharma and Gedeon, 2012).

Assessing alterations in eye blink frequency has been suggested as a method to gauge fatigue. Blink rates seem to rise proportionally to the duration of tasks demanding vigilance. Elevated blink rates, decreased blink intensity, and prolonged eye closure frequencies have likewise been linked to higher error rates during cognitive task execution (DeLuca, 2005). Additionally, Zhao et al. (2023) study revealed that fatigue escalation leads to increased blink duration followed by a subsequent decrease.

3.2.2 Facial features

Non-verbal gestures and facial expressions offer valuable insights into individuals' experiences (Romano Bergstrom *et al.*, 2014), particularly regarding stress and fatigue. Reduced facial muscle movements and specific expressions like mouth movements and raised eyebrows can indicate varying stress levels and levels of fatigue (Haisong Gu, Qiang Ji and Zhiwei Zhu, no date; Hashmi and Yadav, 2018; Uchida *et al.*, 2018). While emotion recognition software holds promise for gauging UX, its effectiveness may vary due to individual emotional experiences (Romano Bergstrom *et al.*, 2014). Additionally, notable changes in facial expressions during tasks confirm the connection between facial expression and mental workload (Shishov, 2017). Despite these insights, the literature lacks extensive exploration of facial features for assessing workload and attention. While promising, facial recognition software should be complemented by other methodologies for a comprehensive UX assessment (Romano Bergstrom *et al.*, 2014).

3.2.3 Speech analysis

Assessing determinants of CFPW like stress levels via speech analysis offers a non-invasive, less intrusive, and cost-effective approach. Voice attributes utilized in stress modelling encompass parameters such as volume, fundamental frequency, zero-crossing rate, jitter, and energy frequency ratios (Sharma and Gedeon, 2012).

Speech measures, despite their potential, are underexplored in workload assessment due to the complexity of accurately quantifying speech elements. Among studied parameters like pitch, rate, and loudness tend to increase with task complexity. However, limited research in this area challenges the reliability of workload assessments relying solely on speech metrics (Miller, 2001).

In fatigue assessment, speech analysis detects changes in voice characteristics sensitive to fatigue levels. Parameters like voice pitch, rate, and loudness typically increase with fatigue, while clarity and articulation decrease (Greeley *et al.*, 2006, 2007; Shintani and Ogoshi, 2023).

Regarding attention, speech analysis examines parameters such as speech rate, pitch, and clarity. Higher attention correlates with increased speech clarity and articulation, while decreased attention may manifest as slower speech rate and lower pitch (Sussman, 2017).

3.2.4 Skin conductance

Skin conductance, also referred to as EDA or Galvanic Skin Response (GSR), is widely employed in psychophysiological assessments due to its ease of use and non-invasiveness. It primarily assesses the activity of the sympathetic nervous system (SNS), which is responsible for the "fight-or-flight" response triggered by emotionally charged stimuli (Romano Bergstrom *et al.*, 2014). This measurement involves evaluating the skin's electrical conductance by assessing electrical potentials between electrodes placed on the skin (Sharma and Gedeon, 2012). Sweat secretion, indicative of heightened emotional arousal, is quantified through EDA, with greater sweat release observed during intense arousal. EDA data can be collected from various body parts such as the finger, wrist, or palm (Sharma and Gedeon, 2012; Romano Bergstrom *et al.*, 2014). EDA is associated with various emotional states and correlates with self-reported arousal levels. Phasic activity, characterized by rapid sweat secretion in response to specific stimuli, and tonic changes in arousal, serving as baseline measures, contribute to EDA assessments. However, analyzing tonic and phasic activity dynamically poses challenges and often requires trained experts. Issues like activity overlaps and inadequate threshold values are common in EDA assessments. Techniques such as summing amplitudes of skin conductance responses (SCRs) are common but not entirely accurate. Integrating SCR calculations provides more precise data analysis. Further research is needed to fully explore EDA's potential in measuring UX, and researchers are encouraged to adopt best practices for its assessment and interpretation (Romano Bergstrom *et al.*, 2014).

Under stress, there is an elevation in skin conductance due to heightened moisture on the skin's surface, resulting in increased electrical conductivity. Conversely, skin conductance decreases when the individual experiences reduced stress levels (Sharma and Gedeon, 2012). GSR has been validated as a reliable stress indicator, with increased GSR values signalling stress and decreased values indicating lower stress levels (Hashmi and Yadav, 2018).

3.2.5 Brain activity

There exist multiple methods for measuring brain activity, such as fMRI, MEG, PET and EEG, with each being beneficial in distinct circumstances. (Sharma and Gedeon, 2012; Romano

Bergstrom *et al.*, 2014). Among these, EEG stands out as the most frequently employed method owing to its superior temporal resolution, non-invasive equipment, and affordability (Sharma and Gedeon, 2012).

3.2.5.1 Electroencephalography

EEG serves as a powerful tool for real-time monitoring of users' emotional states, particularly in laboratory settings, owing to its non-invasive nature and increasing affordability driven by technological advancements. Unlike other neuroimaging techniques, EEG offers ease of use and mobility, making it accessible to users. Notably, EEG detects frustration during usability issues and measures emotional engagement with products (Romano Bergstrom *et al.*, 2014).

Consumer EEG products analyse EEG electrical bands to measure a user's mental state, with software suites automating the calculation of these bands to determine emotional states accurately. EEG research typically involves four primary bands (or frequency ranges) —delta (1–4 Hz), theta (4–8 Hz), alpha (8–14 Hz), and beta (10–30 Hz)—each associated with different states of consciousness and cognitive processes (Romano Bergstrom *et al.*, 2014). Beta and alpha waves indicate conscious states, while theta and delta waves signify unconscious states. Additionally, EEG signals capture complex waveforms resulting from neural activity in the brain, providing valuable insights into emotional responses and workload. These waveforms result from the action potentials of synaptic excitations and inhibitions of dendrites. Scalp potentials typically range from 20 to 100 µV, and they are captured by electrode pairs attached to the scalp on both sides of the brain hemisphere. These waveforms exhibit characteristics such as frequency, amplitude, shape, and scalp locations, with age and level of alertness also playing a role in waveform analysis (Sharma and Gedeon, 2012).

EEG's effectiveness in workload assessment is well-recognized, with changes in EEG bands indicating shifts in workload levels. Increased workload is associated with the disappearance of Alpha waves and the emergence of Beta waves. Theta increases while Alpha decreases with heightened workload. Despite its effectiveness, EEG analysis may be affected by physical movements (Miller, 2001).

Additionally, rapid beta wave frequencies, resulting from a decrease in alpha wave frequencies, are recognized as primary characteristics indicating stress, further highlighting the neurological manifestations of stress (Sharma and Gedeon, 2012).

Furthermore, EEG proves useful in assessing ARDs such as ADHD (Rodrak and Wongsawat, 2013), showcasing its versatility in clinical assessments beyond stress and workload evaluation. The ability of EEG to detect specific brain wave patterns associated with ARDs offers valuable diagnostic insights and potential avenues for intervention and treatment.

3.2.5.2 Eletrooculogram

The EOG is primarily utilized to track saccadic eye movements, similar to eye blink rate and closure intervals. Limited research explores its potential for workload assessment, likely due to its intrusive nature. While it shows promise in indicating visual workload, further studies are needed to compare its results with other visual workload measures. However, implementing EOG tests can be costly (Miller, 2001).

Also, in the context of sleep-related fatigue, polysomnography (PSG) emerges as a standard clinical method, incorporating various sensors such as actigraphs, EOG, headband EEG, electrocardiogram (ECG), and limb electromyogram (EMG) to monitor sleep patterns and fatigue during sleep. PSG facilitates the comprehensive analysis of sleep quality and related fatigue, although its practical application in real-world occupational settings is limited due to physical and mobility constraints (Zhu *et al.*, 2017).

A review of electroencephalography signals approaches for mental stress assessment is presented in (Attar, 2022) where a summary of the above-mentioned patterns can be found.

3.2.5.3 Functional Near-Infrared Spectroscopy

Functional near-infrared spectroscopy (fNIRS) can be used to assess mental workload and stress. Several studies have demonstrated the potential of fNIRS to measure changes in mental workload with increasing validity (Peck *et al.*, 2014; Causse *et al.*, 2017; Alsuraykh *et al.*, 2018; Parent *et al.*, 2019). fNIRS measures the oxygenated (HbO_2) and deoxygenated (HHb) haemoglobin in the blood supply of the brain, which has been shown to discriminate between various mental effort levels (Causse *et al.*, 2017). Variations in blood flow measured with fNIRS have been associated with the engagement of executive functions and working memory load (Causse *et al.*, 2017). When used in valid environments, fNIRS has shown changes in oxygenation due to large increases in task difficulty (Causse *et al.*, 2017). However, smaller differences in task difficulty could not always be reliably differentiated (Causse *et al.*, 2017). Recent work has also demonstrated the feasibility of using convolutional neural networks (CNNs) based on fNIRS-derived signals from the prefrontal cortex to classify mental workload in individuals with mild cognitive impairment (Park, 2023). As the difficulty level of the N-back task increased, the accuracy of the CNNs decreased and prefrontal activity increased (Park, 2023).

So far, fNIRS has shown to be a promising tool for measuring mental workload and stress in real-world settings, although further research is needed to improve its sensitivity to smaller changes in task difficulty and individual differences in neural efficiency (Causse *et al.*, 2017; Park, 2023).

A comparison of mental stress assessment using simultaneous measurement of EEG and fNIRS can be found in (Al-Shargie *et al.*, 2016).

3.2.6 Cardiac activity

3.2.6.1 Heart rate

HR serves as a responsive indicator of both physical and mental fatigue, with beats per minute derived from ECG signals (Mehta *et al.*, 2017). Utilizing basic HR monitors, researchers can measure workload, as HR strongly correlates with physical exertion and moderately with cognitive engagement (Casner and Gore, 2010). While it is influenced by psychological and environmental factors, its reliability varies across studies (Miller, 2001). Additionally, HR can be used to assess stress since it is affected by acute and chronic stress responses (Sharma and Gedeon, 2012).

3.2.6.2 Heart rate variability

HRV offers a non-invasive approach to evaluate cardiovascular conditions and ANS functions, reflecting individuals' adaptability to changes (Sharma and Gedeon, 2012). Its applicability for workload assessment varies, with some studies linking reduced HRV to increased workload, while others report inconclusive findings. Challenges arise from factors like respiration and psychological states, impacting real-time interpretation (Miller, 2001; Casner and Gore, 2010). Short-term HRV reductions indicate acute stress, with analysis typically focusing on the low-frequency and high-frequency bands, representing sympathetic and parasympathetic nervous system (PNS) activity, respectively (Sharma and Gedeon, 2012).

3.2.6.3 Electrocardiogram

The ECG is a highly sensitive method for monitoring heart activity, providing a detailed graphical representation of the electrical impulses generated by ions flowing through cardiac muscles. These impulses, stemming from the heart's depolarization and repolarization processes, propagate to the body's surface, manifesting as characteristic waves such as the P wave, QRS complex, and T wave. By detecting potential changes between electrodes attached to the body, the ECG captures the heart's electrical stimulation cycle, including features like R-R intervals utilized to assess HRV. Einthoven's Triangle aids in configuring leads for desired information, with Lead I commonly used for HRV assessment due to its comprehensive waveform representation (Sharma and Gedeon, 2012).

In terms of physiological responses, the SNS and PNS play crucial roles in maintaining bodily stability. Stress triggers SNS activity, leading to increased HR, while PNS activation promotes relaxation (Hashmi and Yadav, 2018). ECG measurements offer advantages in assessing stress levels, with lower ECG wave amplitudes indicating heightened stress due to vasoconstriction, where peripheral blood vessels constrict (Hashmi and Yadav, 2018). This physiological response serves as a measurable indicator of stress levels and is observed during stressful situations (Sharma and Gedeon, 2012; Hashmi and Yadav, 2018).

Moreover, ECG serves as a valuable tool in fatigue assessment, alongside EMG, for evaluating physical fatigue (Mehta *et al.*, 2017; Zhu *et al.*, 2017; Zhao *et al.*, 2023). Baseline HR variations pose challenges in direct comparisons across individuals, emphasizing the importance of standardizing measurements against baseline values (Sharma and Gedeon, 2012). Overall, ECG provides valuable insights into stress levels and physical fatigue, offering a comprehensive perspective on individuals' physiological responses in various contexts.

3.2.7 Performance measurement

Performance measures of workload encompass primary and secondary task assessment methods. Primary task measures directly evaluate the operator's performance on the task of interest, focusing on speed, accuracy, reaction times, and error rates. However, they may not fully capture the adaptive response to stress or changes in task demands. Secondary task measures provide insight into the remaining operator capacity during primary task performance, aiding in workload diagnosis. Careful selection of secondary tasks is crucial to ensuring they complement rather than interfere with the primary task. Both primary and secondary measures contribute to understanding operator workload, with primary task performance being more extensively studied and easier to measure accurately. However, the incorporation of formal measurement theory in evaluating secondary task workload paradigms is necessary for comprehensive assessment. Overall, a combination of primary and secondary task measures provides a holistic view of operator workload and performance (Miller, 2001; Cain, 2007).

Decreased task performance is often associated with reduced attention to the task at hand (Fuermaier *et al.*, 2021). Additionally, induced fatigue, such as from demanding cognitive tasks, leads to cognitive decline in planning and an increase in perseverative errors compared to non-fatigued individuals. Moreover, fatigue induces shifts towards lower-effort, higher-risk responses post a simulated workday. Long work hours correlate with increased operator errors, notably in 12-hour shifts in nuclear power plants. Therefore, there is a performance decrement with fatigue augmentation (DeLuca, 2005).

3.2.8 Other primary measures

The primary measures discussed in this section are not considered reliable when used independently (Sharma and Gedeon, 2012). Typically, they are employed in combination with other primary measures explored above.

3.2.8.1 Blood pressure

BP indicates the force exerted on blood vessel walls by circulating blood, fluctuating between systolic (peak) and diastolic (lowest) pressure levels (Sharma and Gedeon, 2012). While less commonly used for workload assessment due to its intrusive nature, BP rises with increasing workload, primarily reflecting sympathetic autonomic activity (Miller, 2001). Elevated BP has been linked to increased stress levels, with studies showing (Sharma and Gedeon, 2012; Hashmi and Yadav, 2018).

The literature suggests that BP is less commonly utilized as a measurement for attention or fatigue compared to other physiological indicators like pupil dilation. While BP may increase with stress and workload, its association with attention or fatigue is not as extensively studied or established.

3.2.8.2 Blood Volume Pulse

Blood volume refers to the quantity of blood within a tissue over a specific period. Blood Volume Pulse (BVP) measures light reflection from the skin's surface, indicating blood flow variations post each heartbeat (Sharma and Gedeon, 2012). Changes in BVP correlate with stress levels; decreased BVP aligns with heightened stress, while increased BVP indicates lower stress (Sharma and Gedeon, 2012; Hashmi and Yadav, 2018).

3.2.8.3 Electromyography

EMG records the electrical signals generated by active muscles, specifically muscle action potentials (Sharma and Gedeon, 2012). It can be used to assess fatigue (Zhao *et al.*, 2023) and stress(Sharma and Gedeon, 2012).

3.2.8.4 Skin temperature

Skin temperature (ST) serves as a marker for fatigue assessment (Mehta *et al.*, 2017). Additionally, studies reveal a negative correlation between ST and stress, with ST rising as stress decreases and declining as stress increases (Sharma and Gedeon, 2012; Hashmi and Yadav, 2018).

3.2.8.5 Respiration

Respiration rate and volume serve as stress indicators but are often combined with other physiological metrics for comprehensive assessment (Sharma and Gedeon, 2012). While, respiratory rate, indicative of mental workload, typically increases with workload, while airflow volume and carbon dioxide concentration may decrease. However, conflicting evidence exists regarding airflow volume's response to workload (Miller, 2001). Various methods, such as oxygen uptake devices (Zhao *et al.*, 2023) and respiratory inductance plethysmography, are utilized for assessing fatigue (Mehta *et al.*, 2017), along with posture and activity monitoring (Völker, Kirchner and Bock, 2016; Mehta *et al.*, 2017).

3.2.9 Conclusions

Various objective measures, including physiological responses such as HR, skin conductance, and brain signals, along with observable changes in facial expression, voice, or behaviour, offer reliable means of assessing determinants of CFPW. Alternatives to sensors, such as smartphone-based approaches, are also being explored (Goyal *et al.*, 2016). These advancements aim to address issues like physical activity confounding and equipment intrusiveness, enhancing the effectiveness of factors recognition in real-world settings.

Table 5 to 8 presents the ranking of primary measures used for evaluating the determinants of CFPW.

Table 5 – Empirical ranking of primary measures for stress assessment. Adapted from: Sharma and Gedeon (2012); Hashmi and Yadav (2018).

Rank	Objective Measures for Stress
1	Hear Rate Variability
2	Galvanic Skin Response
3	Electroencephalography
4	Pupil Dilation
5	Speech analysis
6	Gaze
7	Facial expression
8	Blood Pressure
9	Skin Temperature
10	Blood Volume Pulse
11	Blinks
12	Respiration
13	Eletromyography

The ranking of objective stress assessment measures prioritizes physiological indicators that have been shown to be sensitive to ANS activity and emotional arousal. HRV is the first because it directly reflects ANS modulation, providing insights into stress reactivity and control. GSR or EDA follows closely, providing a solid indicator of sympathetic arousal, especially in emotionally intense settings. EEG is ranked third for collecting neural correlates of stress responses and emotional states. Pupil dilation is ranked fourth, thanks to its ability to respond to cognitive and emotional processes. The next step is speech analysis, which uses voice features to detect stress-related changes in vocal patterns. Gaze measurements follow, providing indirect but useful information about attentional allocation and emotional engagement. Facial expressions, despite indicating emotional states, are ranked lower due to their subjective interpretation and environmental variability. BP, ST, and BVP are ranked lower, demonstrating their importance in stress evaluation while also considering their indirect relationship with emotional arousal. Blinks, respiration, and EMG are listed at the end, acknowledging their possible contributions but recognizing their secondary roles in stress detection when compared to other physiological measurements.

Table 6 – Rank of primary measures for workload assessment. [Original source]

Rank	Objective Measures for Workload
1	Electroencephalography
2	Pupil dilation
3	Blink metrics Gaze metrics
4	Heart Rate Variability
5	Performance measurements
6	Respiration
7	Speech analysis
8	Blood pressure
9	Facial features

The proposed order of objective measures for workload assessment reflects a consideration of their respective effectiveness in capturing cognitive and physiological responses associated with task demands. EEG occupies the top position due to its direct insight into brain activity, offering real-time monitoring of cognitive states. Following EEG, pupil dilation stands out as an immediate physiological response to cognitive load, providing a reliable indicator of mental effort. Blink metrics, placed third, offers complementary information, particularly in tasks requiring sustained visual attention. Gaze metrics follow, providing valuable data on visual attention allocation. HRV ranks fifth, acknowledging its potential in capturing ANS modulation but recognizing its variability in workload assessment contexts. Performance measurements, although not purely physiological, offer a practical indicator of task proficiency and cognitive engagement. Respiration and speech analysis follow suit, contributing to the multi-modal assessment of workload. Blood pressure, while indicating physiological arousal, is placed lower due to its less direct association with cognitive processes. Finally, facial features are positioned last, acknowledging their relevance in emotional expression but considering their indirect link to workload assessment. This order aims to optimize the balance between physiological relevance and practical applicability in evaluating workload across diverse task contexts.

Table 7 – Rank of primary measures for attention assessment. [Original source]

Rank	Objective Measures for Attention
1	Pupil Dilation
2	Gaze metrics
3	Blink metrics
4	Performance Measurements
5	Speech Analysis

The ranking places pupil dilation as the most effective objective measure for assessing attention due to its direct correlation with cognitive and emotional fluctuations. Following pupil dilation, gaze analysis, particularly fixations and saccades. Performance measurements are ranked next as they offer a holistic evaluation of attention encompassing speed, accuracy, reaction times, and error rates, providing direct feedback on task engagement and cognitive load. Blink metrics such as its frequency, although informative, is placed after performance measurements as it offers more specific insights into attentional shifts and cognitive processing, which may be limited in scope compared to overall task performance. Finally, speech analysis is positioned last as it primarily focuses on vocal attributes, which may not fully capture the nuances of attentional processes compared to other measures like pupil dilation and gaze analysis.

Table 8 – Rank of primary measures for fatigue assessment. [Original source]

Rank	Objective Measures for Fatigue
1	Blink
2	Gaze
3	Pupil dilation
4	Facial features (expressions)
5	Performance measurements
6	Respiration
7	Skin temperature
8	Speech analysis

The proposed ranking prioritizes measurements according to their perceived efficacy in identifying fatigue. Blink measurements, as the primary sign, provide direct insight into ocular and cerebral weariness, indicating decreased concentration levels. Following, gaze metrics provide useful information by identifying alterations in visual focus, which are influenced by fatigue progression. Pupil dilation, while initially responsive to workload, tends to decline over time as fatigue sets in, reducing its dependability in advanced fatigue stages. Facial expressions provide additional indications, although these are impacted by variables other than fatigue. While performance assessments can indicate exhaustion, they may be less sensitive than ocular or physiological indicators. Respiration patterns and skin temperature variations, while potentially significant, may lack specificity or be impacted by external variables. Finally, while speech analysis can detect changes in speech patterns, it may be more difficult to properly correlate them with fatigue levels than more directly related measurements of attention and fatigue.

3.3 Subjective versus Objective methods

Table 9 provides a concise comparison of methodologies discussed in subsections 3.1 and 3.2. Questionnaires and scales are categorized under "Scales," while facial features, speech analysis, skin conductance, brain and heart activity, and other primary measures like BP are grouped under "Primary Measure." This categorization leads to variations in feature descriptions. For example, HR and BP are moderately priced and user-friendly with immediate sensitivity. In contrast, cortisol levels, obtained from blood samples, require costly equipment and professional handling, with delayed sensitivity due to sample processing time. Furthermore, fMRI is expensive, complex, and non-portable compared to ECG.

Objective measures, while pricier, offer superior accuracy and reliability compared to subjective ones. Among the objective methods discussed, eye tracking emerges as the most effective when evaluating the presented features, boasting better cost-effectiveness than subjective measures.

Taking this into consideration, for HCI in occupational settings, eye tracking seems to be the best choice for assessing determinants of CFPW.

Table 9 – Qualitative comparison of the determinants of CFPW assessment, grouped by subjective versus objective methos.

Methods / Features	Subjective			Objective		
	Interview	Focus group	Scales	Eye tracking	Primary measure	Performance measurement
Cost	Low	Low	Low	Moderate to High	Moderate to High	Low
Ease of Usage	Easy	Moderate	Easy	Moderate	Easy to complex	Easy
Accuracy	Variable	Variable	Variable	Moderate	High	Moderate
Reliability	Low	Low	Low	Medium	High	Medium
Invasiveness	Non	Non	Non	Low	High	Non
Time Sensitivity	Delayed	Delayed	Immediate	Immediate	Immediate to delayed	Immediate
Portability	Portable	Portable	Portable	Portable	Semi to non-portable	Portable
Interpretation Complexity	Easy	Easy	Easy	Complex	Easy to complex	Easy
Temporal Resolution	Minutes	Hours	Seconds to minutes	Milliseconds	Seconds to hours	Seconds to minutes

4 Part 1 – Validation of Pupil Labs Core eye tracking glasses

Digital pupillometry, specifically digital infrared pupillometry, which encompasses a device equipped with a light-emitting diode (LED) light source and a digital infrared camera, stands as the gold standard for assessing the PLR (McGrath *et al.*, 2022). However, these advanced systems often come with a significant price tag and require specialized training for proficient operation (McGrath *et al.*, 2022). For example, the PlusOptix A16 from Nuremberg, Germany, distinguishes itself with specialized equipment featuring binocular infrared photorefraction. This setup enables the measurement of pupil size in infants (from 5 months onwards) and adults alike. The device is versatile, accommodating use over glasses and contact lenses, and capable of performing monocular readings. It allows for simultaneous measurement of both eyes from one meter away in less than a second, ensuring accurate recordings even with non-dilated pupils (Plusoptix, 2024).

In the realm of ophthalmic and OSH research, the validation of eyeglasses, such as the Pupil Labs Core (PLC), is of paramount importance. Leveraging the capabilities of PlusOptix A16, these eyeglasses can be rigorously tested and validated for their efficacy and precision in monitoring pupillary responses.

4.1 Methodology

The methodology includes details such as sample and equipment descriptions and the procedures employed.

4.1.1 Participants

The study included a diverse range of ages and individuals with various vision features. The participants included adults who could comprehend the study details and provide informed consent, as well as children who participated under parental supervision. In addition to collecting data on sex and age, participants were asked about their use of lenses or glasses. This project underwent an ethical review and was approved by the ethics committee of the Polytechnic of Porto School of Health.

4.1.2 Equipment's specifications

The PLC eye tracking glasses (Figure 20), hereafter referred to as PLC, features a 0.60º accuracy (with calibration), 0.02º precision, and eye cameras operating at 192 x 192 pixels with a refresh rate of 200 Hz.

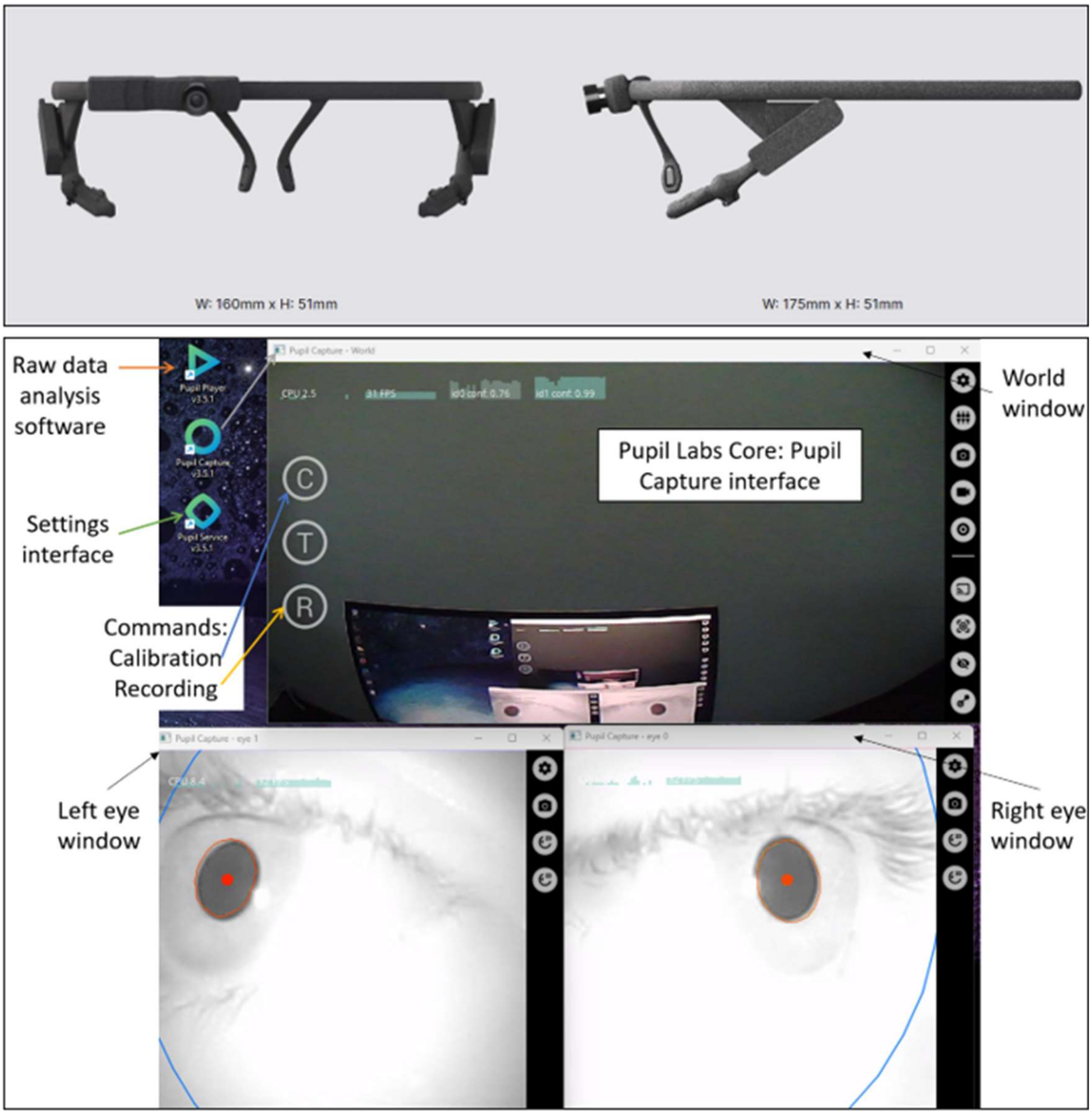

Figure 20 – Above, Pupil Labs Core (PLC) eye tracking glasses dimensions (W: width; H: height). Adapted from Pupil Labs (2024). Bellow, PLC software to view and capture real-time gaze and pupil data [Original image].

The PlusOptix A16 equipment (Figure 21), hereafter referred to as PO, features unique 54 LED illumination. It has a dynamic acquisition time averaging 0.5 seconds and a measuring distance of 1 meter with a tolerance of ± 5 cm. The system supports both monocular and binocular measurements, enhancing accuracy in assessing physical conditions. Pupil sizes ranging from 3 to 8 mm can be measured in 0.1 mm increments (Plusoptix, 2024) .

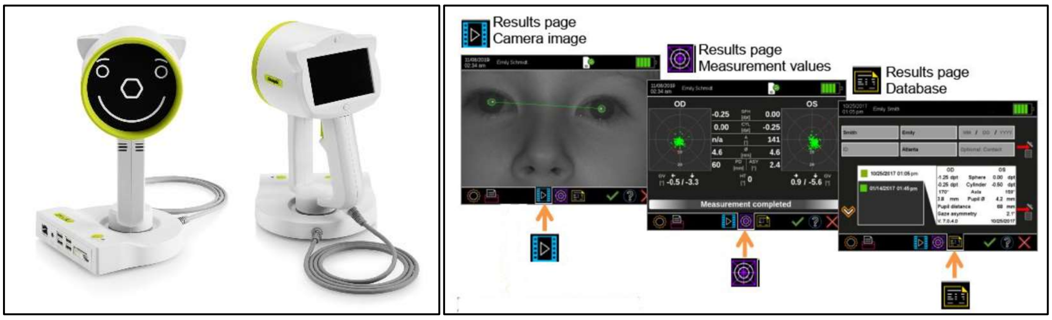

Figure 21 – On the left, the PlusOptix A16 equipment (in two distinct perspectives); on the right, snapshots of the equipment’s screen showing the measurement results. Adapted from Plusoptix (2024).

4.1.3 Procedure

The steps that were followed for each participant, during equipment validation sessions, are represented in the pipeline of Figure 22, which will be described in detail.

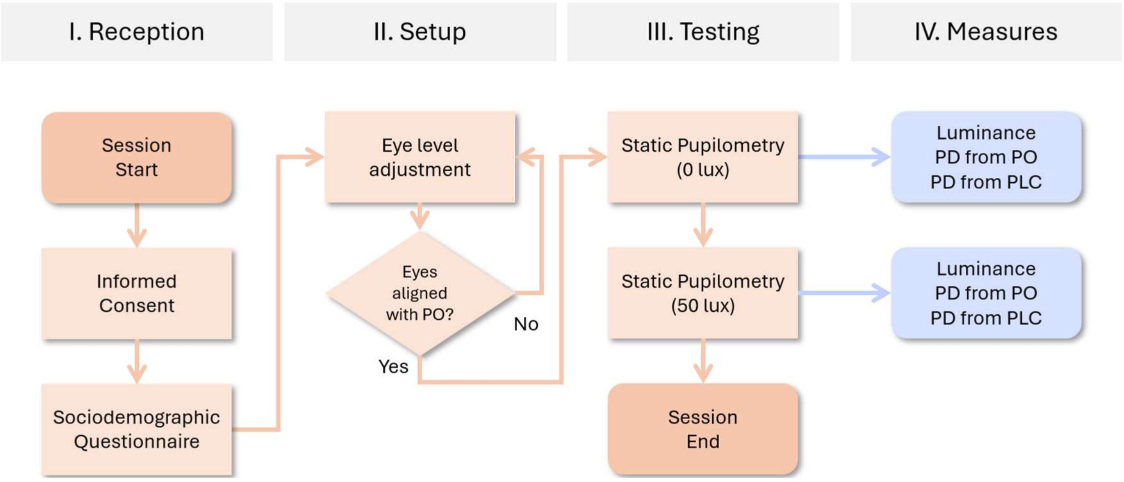

Figure 22 – Pipeline for equipment validation sessions.

After obtaining informed consent, participants were seated, and their seats were adjusted so that their eyes were level with the PO equipment. Participants wore the PLC glasses while looking at the PO equipment for data collection. According to the manual instructions, participants were positioned with their noses and knees aligned with the device. They were instructed to maintain focus on the hexagonal "nose" in the smiley face displayed on the equipment throughout the measurements.

Initially, participants were asked a brief verbal questionnaire regarding their age, sex, and use of glasses. Following this, static pupillometry was conducted under two standardized illumination conditions: scotopic (0 lux) and low photopic (50 lux, typical for medium/low light indoor environment). At each illumination level, PD measurements were taken and compared with those from the PLC glasses for analysis.

Additionally, the illuminance at eye level was measured for each light condition in every participant using a Delta-OHM HD 2302.0 luxmeter. The initial timestamp for PLC recording was also documented. Both systems provide comprehensive analysis capabilities, enabling precise evaluation of pupil dynamics under controlled illumination conditions.

The experimental setup is illustrated in Figure 23.

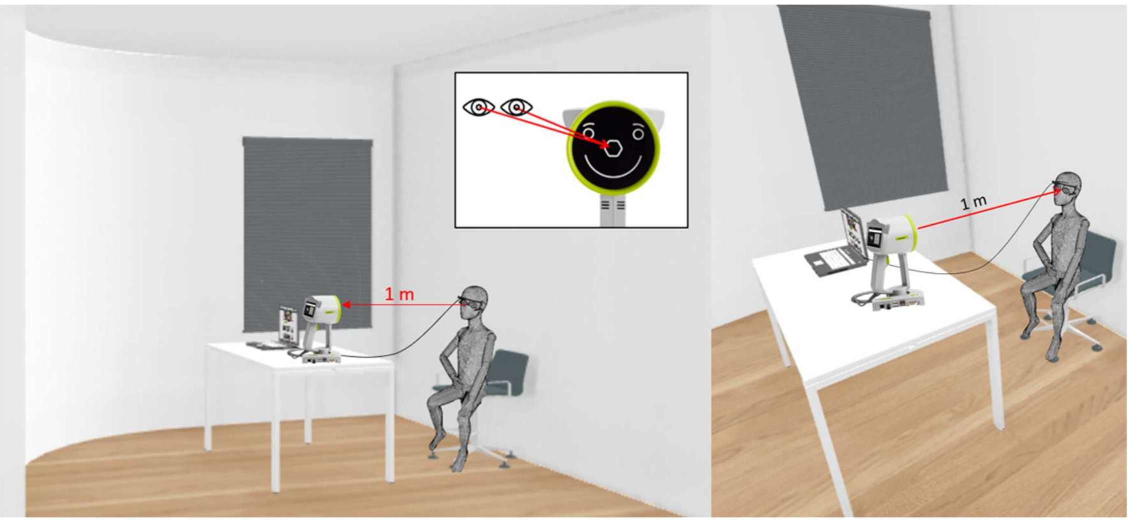

Figure 23 – Setup for Pupil Labs Core eye tracking validation.

4.1.4 Data treatment

The results from the PO equipment were extracted using a PEN, and a CSV file with the measurements was obtained. This file was manually processed to remove non-relevant columns and rows.

For the PLC data, a Python script was used to compile all data into a single file. A flowchart describing the data treatment process is shown in Figure 24. Another Python script was then used to combine the PO and PLC results into a comprehensive file (see flowchart in Figure 25). Participants exclusion from each set for comparison were performed manually.

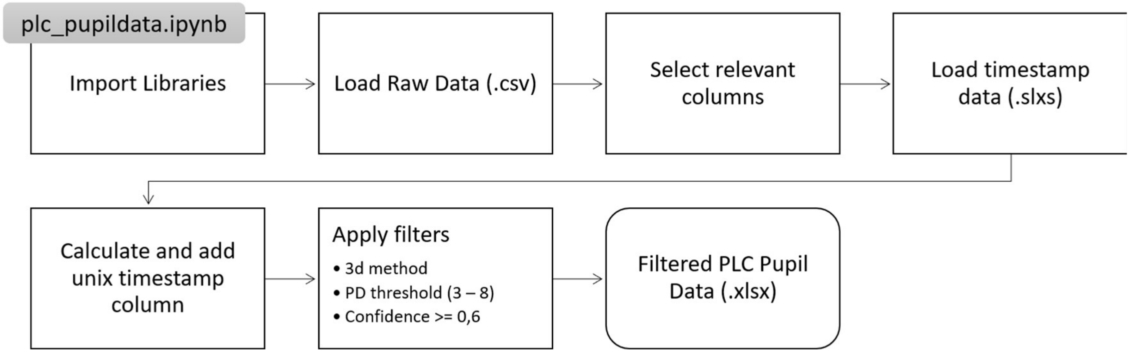

Figure 24 – Flowchart for PLC data treatment script.

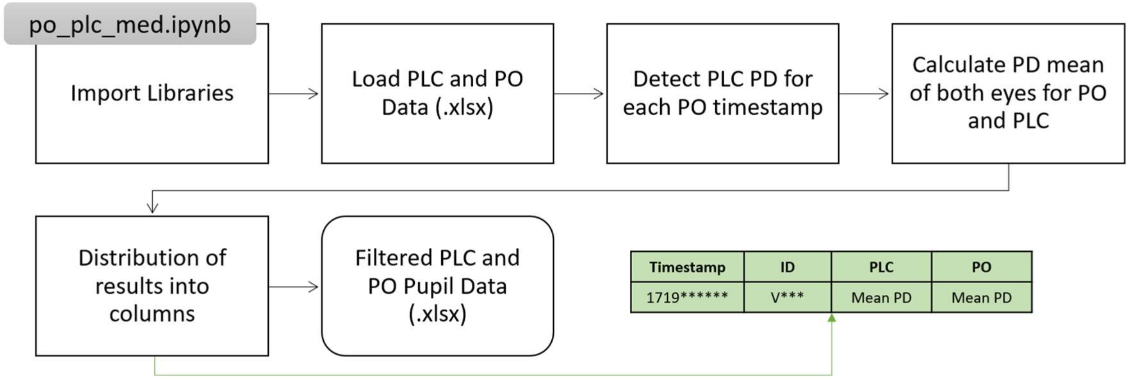

Figure 25 – Flowchart for PLC and PO data compilation script.

Participant exclusions from each dataset for comparison were performed manually. In addition to descriptive statistics calculated in Excel, other statistical analyses were conducted using a Python script (see flowchart in Figure 26).

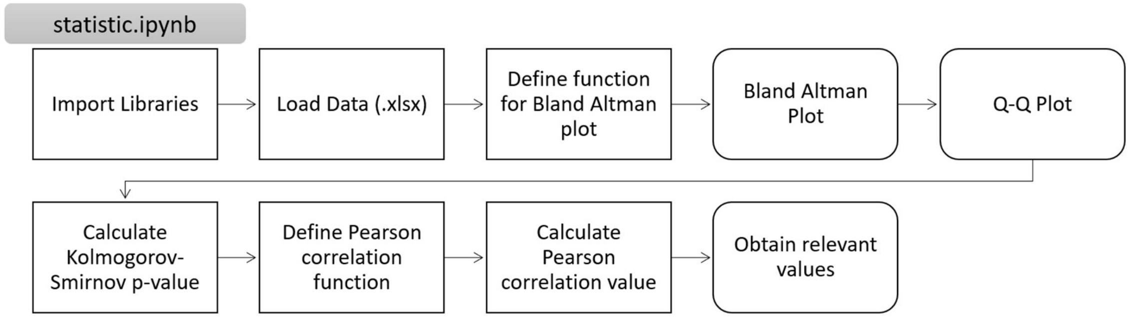

Figure 26 – Flowchart for non-descriptive statistics analysis script.

All Python scripts were created and executed in a Jupyter Notebook environment using Anaconda.

4.2 Results

In this experiment, approximately 130 people were approached on the street and invited to participate at a controlled experiment location, using convenience sampling. Out of these, 118 people accepted the invitation. During the data collection with the PLC glasses, a technical error resulted in the loss of one sample, reducing the total sample size to 117 participants. Additionally, the PO equipment presented inconclusive measures and an excess IR light error in many participants at different light conditions.

Therefore, in this study, participant data underwent rigorous screening and exclusion criteria due to technical and measurement issues. Specifically, 72 % and 76 % of participants were excluded because the PO equipment failed to record their PD, at 50 lux and 0 lux, respectively. Thus, 0 lux condition ha 28 valid measures and 50 lux condition ha 32 valid measures. Consequently, since some samples were excluded, the included samples in the two conditions ended up being different.

For 0 lux conditions, among the participants, 25% wore glasses and 51% were female. The age ranged from 5 to 84 years. The age distribution is displayed on the left of Figure 27. For 50 lux conditions, among the participants, 22% wore glasses and 63% were female. The age ranged from 5 to 53 years. The age distribution is displayed on the right of Figure 27.

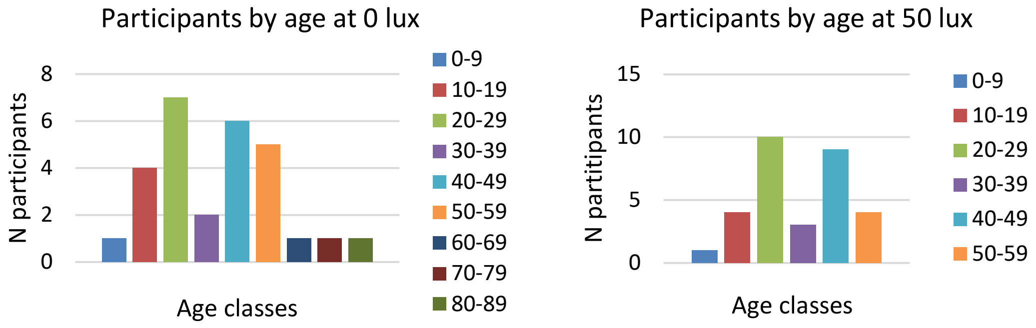

Figure 27 – Age distribution of participants included in scotopic illumination conditions at the left and low photopic illumination conditions at the right.

According to the Q-Q plots, the data for both light conditions follow a normal distribution (Figure 28). This is supported by the Kolmogorov-Smirnov test results, which show no significant deviation from normality. The p-values for the PLC were 0.9427 at 0 lux and 0.9192 at 50 lux, and for the PO, the p-values were 0.9597 at 0 lux and 0.9603 at 50 lux.

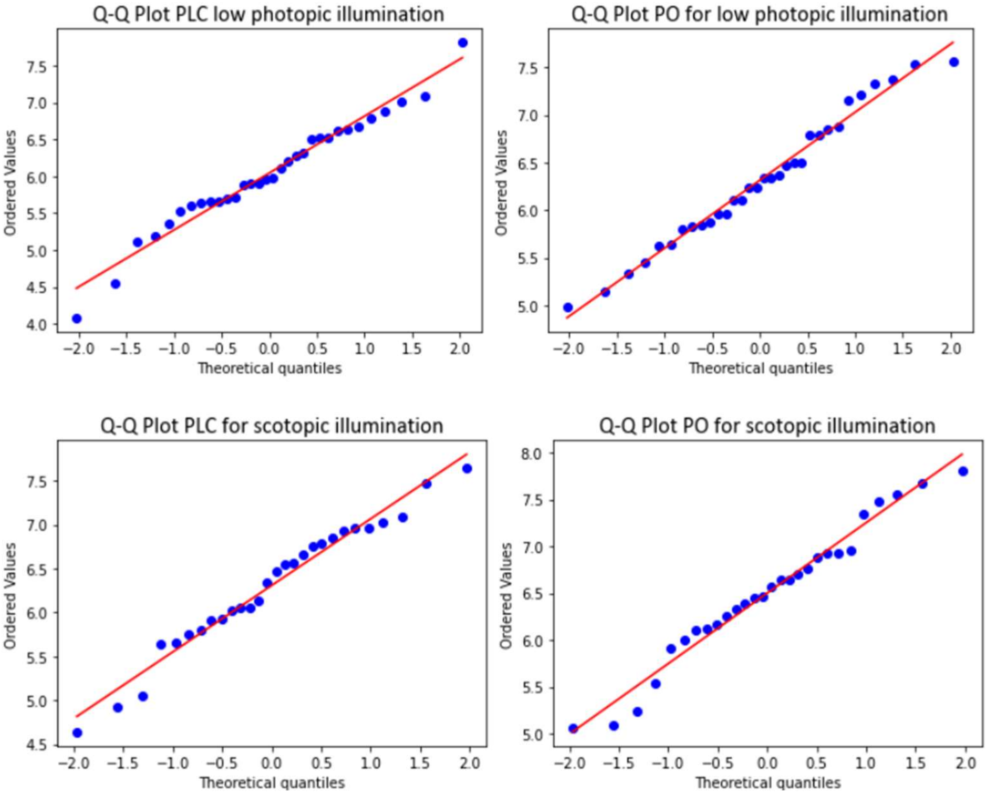

Figure 28 – Q-Q Plot for pupil diameter from both studied equipment's at both illumination conditions. On the left PLC measures for both light conditions and on the left PO measures.

The Pearson correlation values indicate a strong correlation between PO and PLC measurements for both light conditions, with a correlation of r=0.8087 (p<0.01) at 0 lux and r=0.7981 (p<0.01) at 50 lux. Additionally, a Bland-Altman plot was created for both illumination conditions (Figure 29).

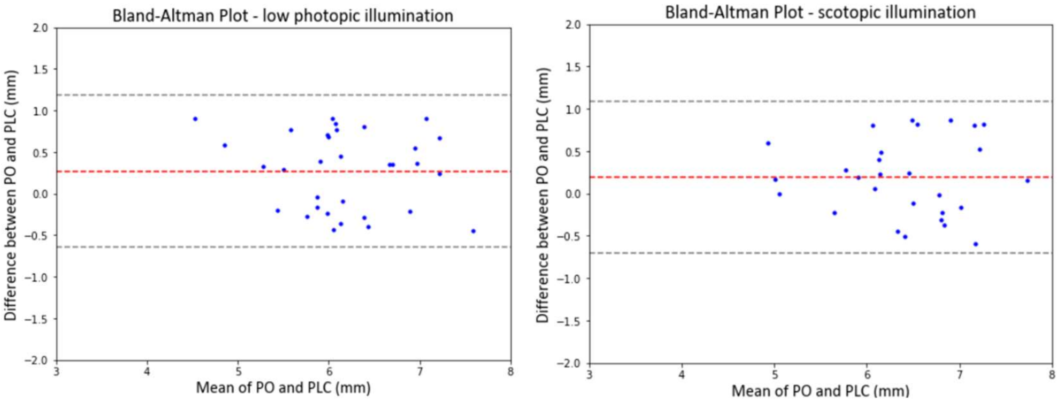

Figure 29 – Bland Altman Plot for both illumination conditions.

4.3 Discussion

This pre-test for PLC validation with PO equipment encountered significant participant loss due to PO equipment errors. The likely cause was the reflection of infrared light from the PO equipment's 54 IR LEDs by the white wall behind participants, exacerbated in low-light environments where the light could not disperse adequately (Kaga *et al.*, 2019). As a result, the PO equipment received infrared reflections, making pupil detection difficult and leading to unreliable measurements. Nevertheless, results from remaining participants consistently show a strong and reliable results between PLC and PO measurements across different lighting conditions.

Firstly, the Quantile-Quantile (QQ) plot is a graphical tool used to compare the distributions of two datasets. For the purpose of comparing measurements from two pieces of equipment the following observations can be made: In terms of linearity, the obtained results show that a similar distribution can be observed, with a clear central tendency despite some spread along the central line; The systematic deviations are not visible; The tails behaviour are not visible showing that both equipment’s follow a (near) linear behaviour across the measurement range; Finally, regarding outliers, there is none, suggesting that the equipment’s are not producing occasional anomalous measurements.

Concerning the Bland-Altman plot, it allows to compare two measurement methods by plotting the differences between the methods against their average. From the obtained results the following observations can be made. With regards to bias, the mean of the differences between the two methods slightly deviates from zero, indicating a systematic bias, by other words, one method consistently measures higher than the other. In relation to the limits of agreement, the obtained results fit within the 95% confidence interval, showing an agreement between the two methods (assuming the differences are normally distributed). The variation band shows an acceptable width. As for patterns in the differences, the obtained results are randomly scattered around the mean difference with no apparent pattern, suggesting that the differences are consistent across the range of measurements. In respect of heteroscedasticity, an increase in the spread of the differences with the magnitude of the measurement is not visible, meaning that the variability in the differences does not depends on the measurement size. Finally, outliers are not visible, pointing to an absence of measurement errors, equipment malfunction, or other anomalies.

The Pearson correlation values approaching 1 and all data points falling within the Bland-Altman plot's confidence interval indicate substantial agreement between the two methods, reinforcing the study's robustness despite initial measurement challenges. While no directly comparable studies exist, previous research has explored comparable methods for instrument validation in various contexts (Jones, 2020; Cuve *et al.*, 2022; Nixon, Thomas and Jones, 2023), presenting similar results.

This study is pioneering in validating PLC equipment for PD measurements. The findings affirm that PLC accurately measures PD in low-light environments. However, comprehensive validation against PO requires conducting tests under higher illumination levels, such as 500 lux or other lighting intensities typical in workplace settings.

4.3.1 Limitations

Timestamps for PLC records were manually documented, which may introduce errors and could potentially account for discrepancies or missing PLC data. Moreover, PLC functions as a continuous monitoring device, so the absence of data at specific moments (seconds) is unlikely to affect its overall performance or final outcomes. Many participants could be excluded from the study due to missing data precisely at the timestamp defined by the PO equipment; however, data from the second before or a brief interval prior were available and used, as the PO equipment can measure either instantaneous values or intervals of seconds.

The low-light environment chosen for the experiment was suboptimal for PO equipment measurements, possibly explaining its inability to detect and measure pupil size in many participants. Nevertheless, the large sample size helped mitigate these limitations, ensuring the validity of the results. Despite losing more than half of the participants due to inconclusive measurements from the PO equipment, the findings remain robust.

4.4 Conclusion

In conclusion, this study contributes to the field by demonstrating the efficacy of PLC equipment under specific lighting conditions, paving the way for future investigations into its applications in diverse environments, outside the laboratory and in the activity specific contexts. To fully validate PLC compared to PO, future studies should incorporate tests under higher illumination levels, such as 500 lux, which are more representative of real-world settings. Despite limitations like manually documented timestamps and exclusions due to inconclusive measures, the study's robust sample size ensures the reliability and generalizability of its findings, emphasizing the potential of PLC in clinical and research applications.

5 Part 2 – Laboratory experiment in a simulated working environment

This chapter includes a description of the methodology, a presentation of the results, and a preceding discussion, culminating in the conclusions drawn from a laboratory experiment conducted in a simulated working environment.

5.1 Materials and Methods

This analytical experimental study seeks to validate PLC for assessing workload, stress, attention, and fatigue by measuring pupil size variations. The primary goal is to compare subjective and objective methods and examine how environmental and task-related factors influence cognitive and physiological responses. The research was conducted in the controlled environment of the Human Factors & Cognition lab (HF&Clab), at TBIO, which is designed to simulate typical working conditions.

5.1.1 Materials

The initial questionnaire was administered using LimeSurvey software and could be completed in either English or Portuguese. The scales used were the DASS-21, the PSWQ, and the Brief COPE. The DASS-21 is a questionnaire that measures depression, anxiety, and stress on a quantitative scale from normal to extremely severe. The PSWQ assesses the state of worry, and the Brief COPE evaluates the coping strategies used by the participant. These tools were essential for assessing the participants' initial mental state, focusing on their levels of stress, tendency to worry, and coping mechanisms. In addition, various physiological and psychiatric factors were evaluated due to their relevance to pupil detection and potential impact. Specifically, the assessment took into account the use and intensity of make-up, the Fitzpatrick scale (Figure 30), body mass index, and any existing mental health diagnoses or substance use.

Figure 30 – Colour bar tool for skin type self-identification, representing every six (I to VI) types in Fitzpatrick scale. Adapted from Gupta and Sharma (2019).

Excel files were used to document participants subjective measurements and environment conditions. Table 10 describes the used equipment's to collect ambient and physiological data and its respective data units.

Table 10 – Data collection equipment's.

Equipment	Brand/Model	Measurand	Unit
Thermohygrometer	VelociCalc Multifuncional 9565-X, TSI	Air temperature Air relative humidity	ºC %
Luxmeter	Delta-OHM, HD 2302.0; - LP 471 phot probe	Luminance in task area, neighbourhood area and at ocular level	lux
Dosimeter	Soundmeter, Bruel & Kjaer 2250-D00	Noise	dB
Spectroradiometer	Gossen-Mavospec Base Spectral	Light temperature	Kelvin
Eye tracking	Pupil Labs Core	Pupil diameter	mm
Echocardiogram	Software Mad@work	Heart rate	bpm

Additionally, in terms of subjective measurements, for workload NASA-TLX questionnaire was used. It has six significant dimensions, and participants answered on a scale of 0 to 100, where 0 is nothing and 100 is a lot, the following questions, for each task:

1. Mental demand: How mentally demanding was the task?
2. Temporal demand: How hurried or rushed was the pace of the task?
3. Physical demand: How physically demanding was the task?
4. Performance: How successful were you in accomplishing what you were asked to do?
5. Effort: How hard did you have to work to accomplish your level of performance?
6. Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

Regarding stress, mental fatigue, and eye strain, a VAS scale was used for subjective measurement. Participants rated how they felt for each on a scale from 0 to 100. Although eye strain itself is not classified as a determinants of CFPW, it was measured in relation to attention outcomes.

5.1.2 Participants

Ninety individuals were invited to participate through email or direct contact. This group included Emmah Cohort students, finalists from various master's programs, researchers, and a diverse range of workers who met the study requirements. Out of the 90 invited, 51 (57 %) agreed to participate.

The participants were working-age adults capable of understanding the study details and providing informed consent. The inclusion criteria required participants to regularly engage in tasks demanding high cognitive workload and use screens for over three hours a day. The objective was to evaluate the accuracy and sensitivity of the methodology across a diverse sample. There were no exclusions for ocular or cardiac conditions, as a convenience sampling approach was used for protocol validation. This project underwent an ethical review and was approved by the ethics committee of the Polytechnic of Porto School of Health.

5.1.3 Experimental conditions

HF&Clab was adapted to create a simulated working environment. For this experiment, a desktop equipped with an external camera was used. The current recommendations for workplace ergonomics were considered, tailoring each subject’s workstation to their anthropometric characteristics. This included adjusting the seat height, backrest, armrests, and the positioning of the keyboard, mouse, and monitor. Lateral views of the setup experiment can be seen in Figure 31.

Figure 31 – Simulated working environment setup.

Noise levels were carefully monitored using a Bruel & Kjaer 2250-D00 sound meter to ensure comprehensive environmental noise control. HF&Clab also had luminaires that allowed for the regulation of illuminance levels. To ensure scenarios with different illuminance levels, while maintaining replicable conditions between subjects, illuminance levels were controlled with a Delta-OHM HD 2302.0 luxmeter and the light colour with the GOSSEN, MAVOSPEC Spectroradiometer.

5.1.4 Procedures

The data collection session followed, for each participant, the pipeline presented in Figure 32, which will be described in detail.

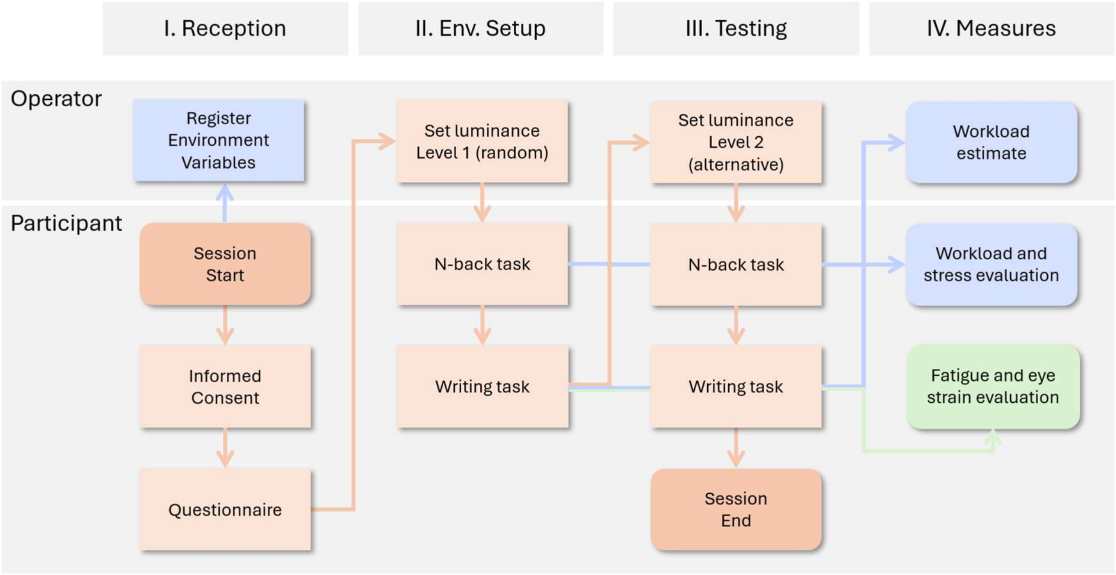

Figure 32 – Pipeline for determinants of CFPW assessment.

After obtaining informed consent and prior to starting the experimental tasks, participants filled out an initial questionnaire (Appendix 2). It was answered on the computer next to the simulation scenario (Figure 31). This evaluation employed three scales to establish baselines for stress, worry, and coping strategies.

Then participants underwent an experiment in two different light conditions. They were randomly assigned to experience 500 lux (Figure 33A) and 300 lux (Figure 33B), to prevent bias. In each condition, participants completed a series of cognitive tasks designed to induce varying levels of cognitive workload. These tasks included two N-back tasks (N=2 and N=3) (Heine *et al.*, 2017; Huang *et al.*, 2018) and a practical email writing task, chosen for their established effects on HRV and cognitive workload. In a N-back task involving letter trials, participants must determine if the current letter matches the letter presented N trials earlier (Gajewski *et al.*, 2018)(Figure 34).

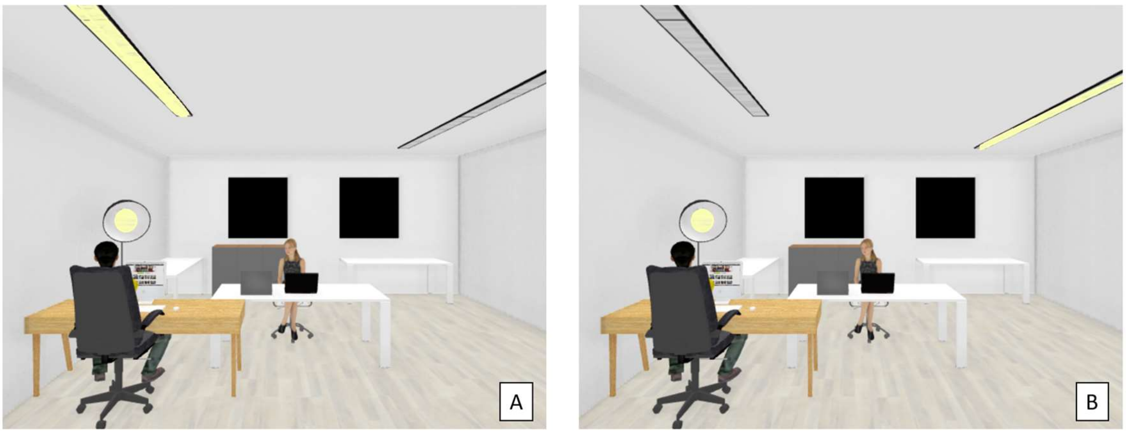

Figure 33 – 3D model of the HF&Clab lighting conditions. A – 500 lux; B – 300 lux.

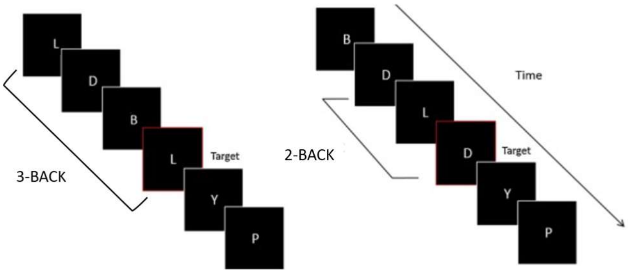

Figure 34 – Basic Operation of the N-Back Test. Adapted from Gilmour et al. (2019).

After completing the tasks in one light condition, participants proceeded to complete the same tasks in the other light condition. The workload and stress experienced by participants during each task were subjectively assessed using the NASA-TLX and VAS scale, respectively, providing a comprehensive measure of the cognitive demand imposed by these activities. In between conditions another two VAS were applied, for fatigue and eye strain (ocular effort).
Furthermore, the email task encompassed two distinct topics to maintain participant engagement and avoid repetition. Likewise, participants were informed that the N-back tasks would present different letter sequences compared to those encountered previously.

ECG data collection was facilitated by the Mad@Work software, previously presented (Ferreira, Rodrigues and Rocha, 2022) which captured HR data and emotional states. For pupillometry, participants used the PLC system.

5.1.5 Data collection

Regarding the initial questionnaire, the questions and responses were collected in numerical code to facilitate data processing, resulting in a CSV file containing the answers from all participants.

The subjective VAS questionnaires for stress, fatigue, and eye strain, were verbally discussed and recorded in the same Excel file, with different sheets for each. Similarly, NASA-TLX scores for each participant were verbally discussed and documented in the Excel file, where each participant had their own sheet. As a result, a new Excel file was created for every group of ten participants. The NASA-TLX Excel sheet was preconfigured to automatically calculate the dimension weights by allowing participants to select their preferences through pairwise comparison. Likewise, workload scores were automatically calculated by entering subjective scores into designated cells for each dimension, with all Excel formulas adhering to the NASA-TLX user manual guidelines.

Real-time measurements such as illuminance, light temperature, air temperature, and relative humidity were also documented in Excel files. One Excel file was dedicated exclusively to illuminance, while another was used for the other conditions. Noise levels were recorded directly on the device.

Regarding the n-back tasks, a TXT file with the answers was formed after every assignment.

For PLC measurements, two records were obtained for each participant, corresponding to each light condition. All files were analysed using the PLC's analysis software to extract raw data for pupil metrics. Consequently, each participant had two PLC files, which were Excel files containing extensive information on pupil metrics.

Lastly, Mad@Work software generated a single folder for each participant, as it was active throughout the entire procedure. In each folder one CSV file had the ECG information.

5.1.6 Data treatment

To process the raw data, a series of Python scripts were developed using Jupyter Notebook within the Anaconda environment. For each set of results a different flowchart was made, to better visualize the data treatment.

For the initial questionnaire, the Fitzpatrick and the questionnaires score was calculated according to the literature (S. H. Lovibond and Lovibond, 1995; Sachdeva, 2009; Pty Ltd, 2021; NovoPsych, 2024). Therefore, the initial questionnaire data treatment (Figure 35) produced one table with the following header: ID; Age; Glasses; Make-up; Beard; Qualitative Body Mass Index (BMI); Medication; Skin type; Stress; Anxiety; Depression; Worry; Dominant.

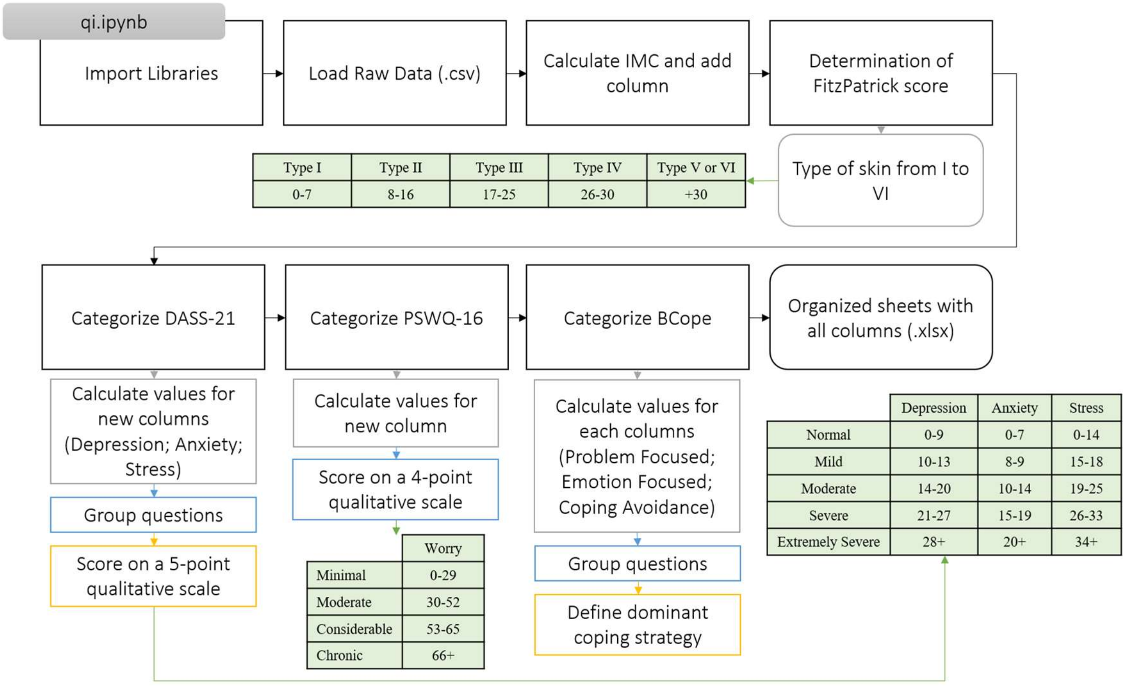

Figure 35 – Flowchart for initial questionnaire data treatment script.

The N-back TXT files data treatment (Figure 36) originated an excel composed by two different sheets, one for each light condition. In each sheet the resultant header was ID, 2-back performances (%) and 3-back performances (%).

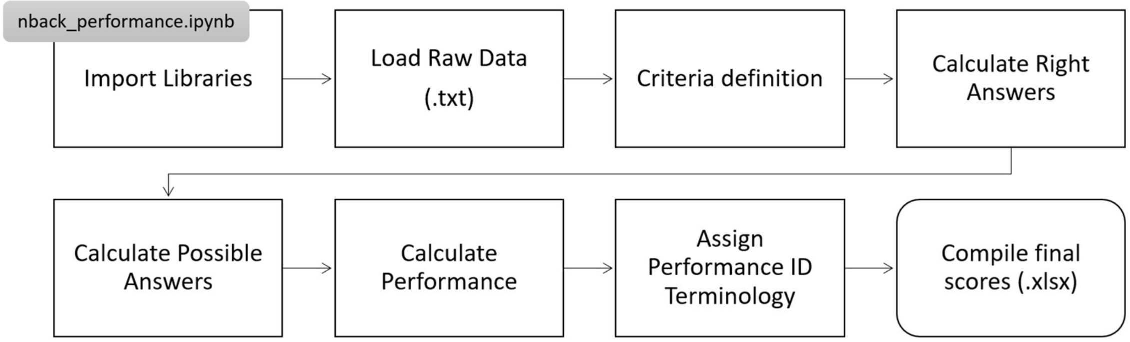

Figure 36 – Flowchart for N-back performance data treatment script.

The NASA-TLX files required a set of scripts (Figure 37), each identical but with different input names for every 10 participants, to select the relevant cells (workload scores for each task in each light condition). Additionally, another script was used to aggregate all outputs from the set of scripts into a single file.

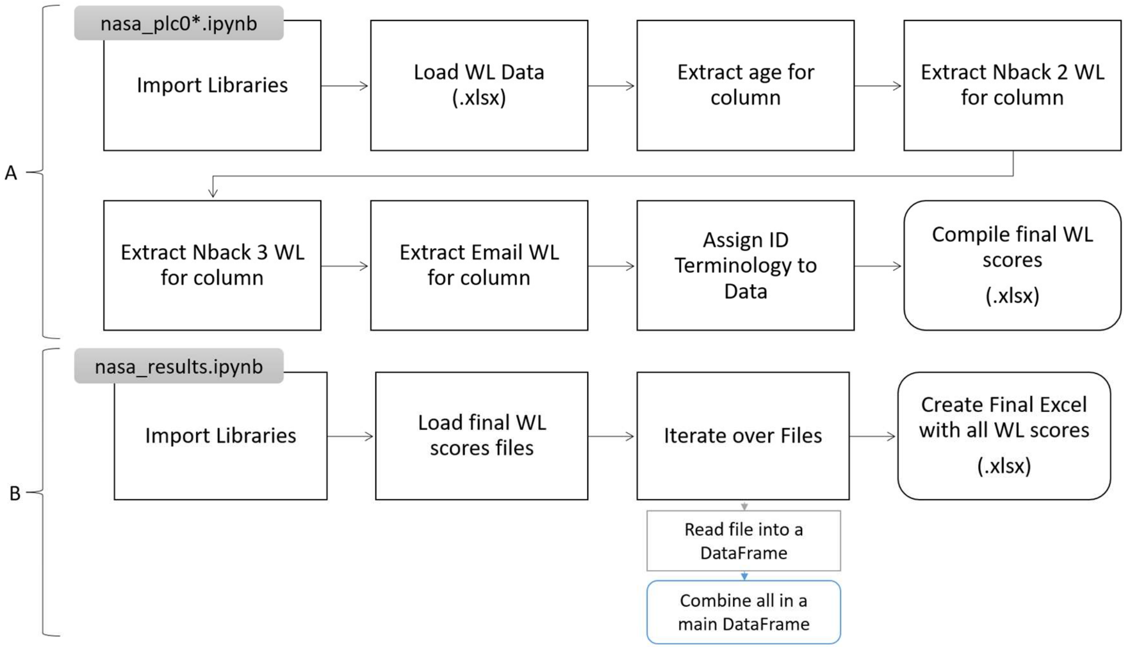

Figure 37 – Flowchart for NASA-TLX data treatment scripts. A – compilation of workload (WL) scores for each 10 participants. B – compilation of all WL scores.

For processing ECG data (Figure 38), two scripts were employed: the first to filter raw data and generate graphs for visual interpretation, and the second to calculate relevant means from the filtered data. According to the flowchart, the first minute of data was excluded. This decision was made because all participants viewed the software operating, and there was a delay in setting up Mad@Work and recording with PLC. Therefore, the first minute was disregarded due to its lack of relevant data.

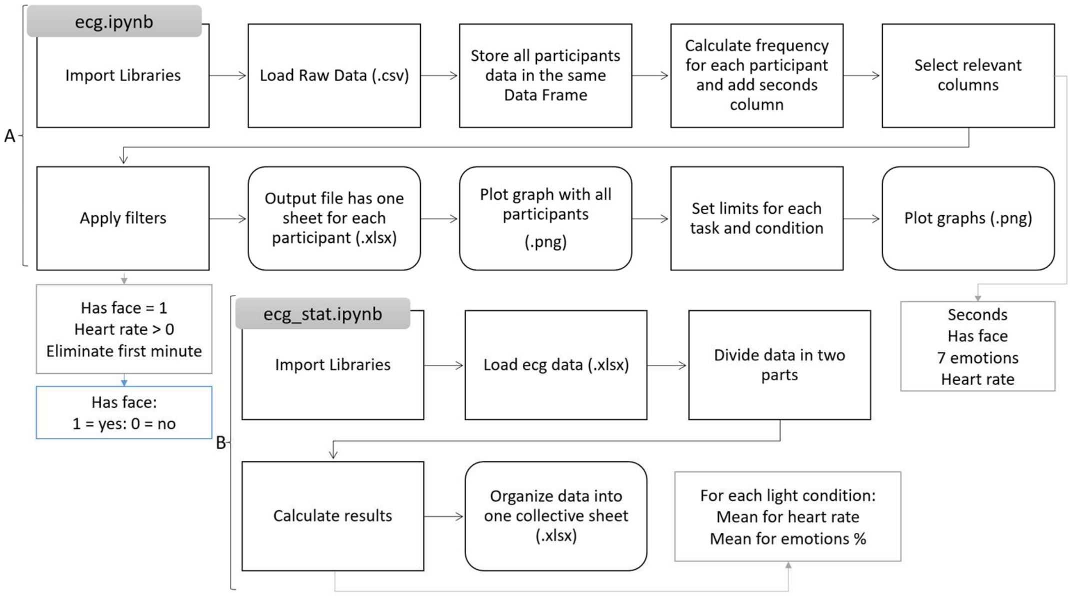

Figure 38 – Flowchart for ECG data treatment scripts. A – Filtering raw data and visual interpretation. B – Final excel compilation and statistical calculation.

Regarding PLC data treatment (Figure 39), three different scripts were used. The pupil size threshold was set between 2 to 8 mm (Lazar *et al.*, 2023), and the task segmentation was defined through graph visualization. The statistical data for each participant, averaged between both eyes for each condition, was then obtained for analysis.

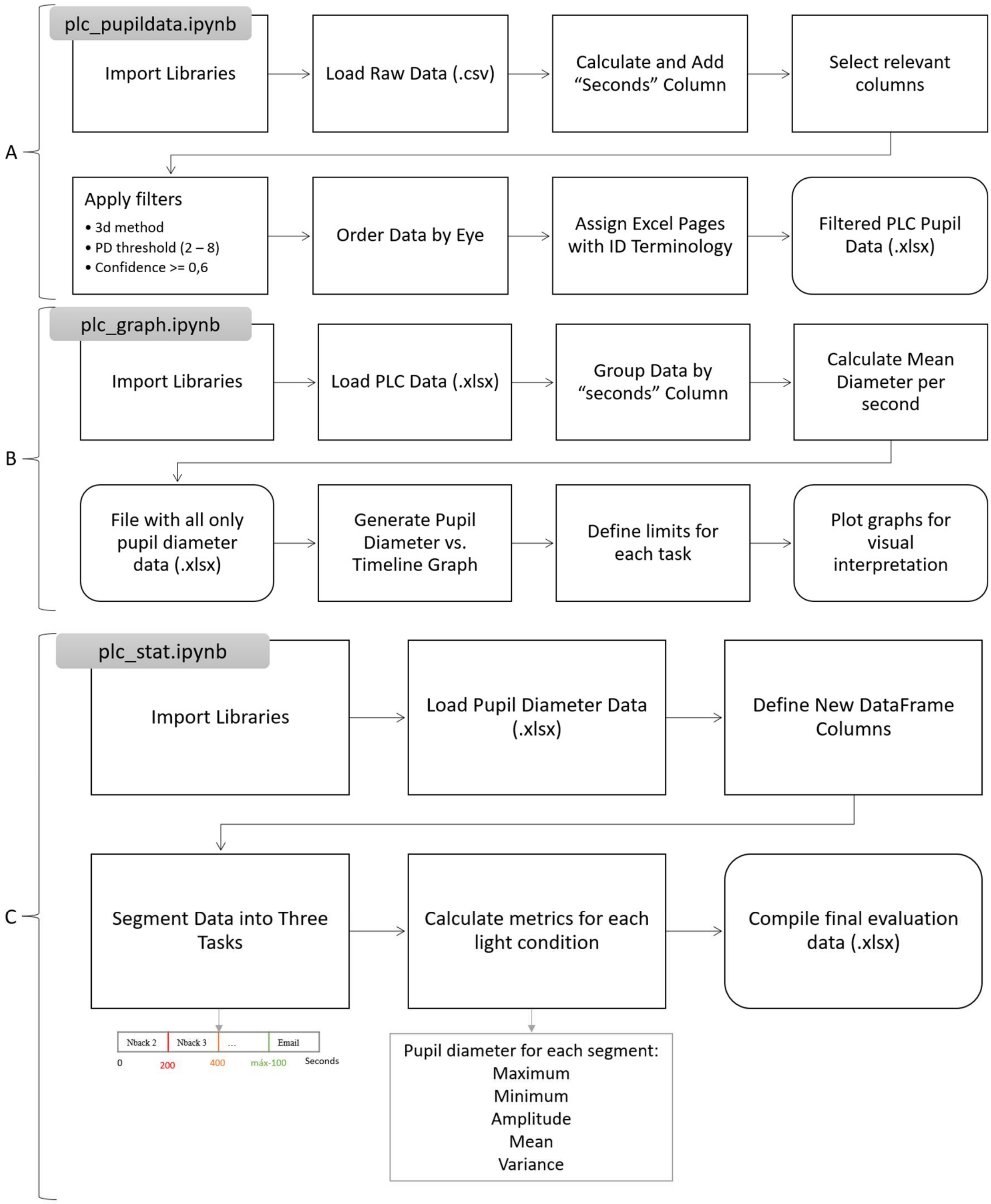

Figure 39 – Flowchart for PLC data treatment scripts. A – Filtering raw data. B – Means calculation and visual results obtention. C - Final excel compilation and statistical calculation.

Finally, the Excel files containing VAS, light temperature, air conditions (relative humidity and temperature), and illuminance were utilized directly without any additional data processing scripts. Illuminance metrics were automatically calculated within Excel following the annotation of the measurements. Mean values for task and neighbourhood area illuminance were calculated for each participant, along with illuminance uniformity. All the previous output files were subsequently analysed using Microsoft Excel.

For non-descriptive statistics another python script was created and executed (Figure 40).

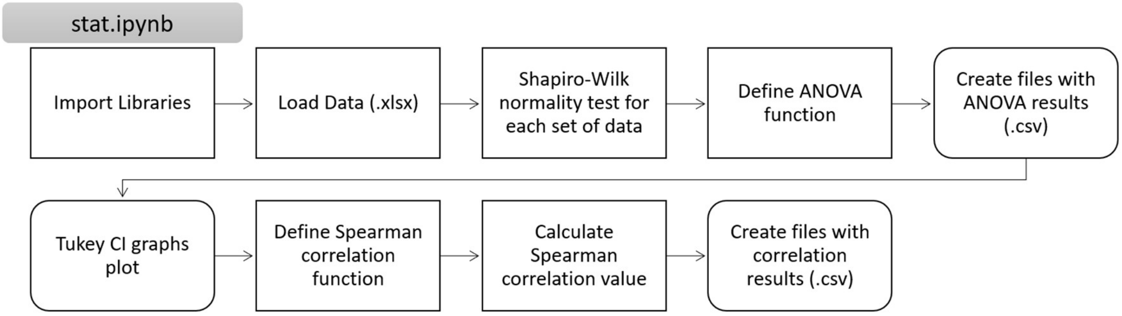

Figure 40 – Flowchart for non-descriptive statistics script.

5.2 Results

This section presents all relevant results from the experiment, divided into sections covering the initial questionnaire, environmental conditions, subjective and objective methods. It culminates in statistical analyses, comparing both light conditions and subjective versus objective methods.

5.2.1 Initial questionnaire

The participant sample initially consisted of 51 individuals, including 30 females and 21 males. However, three participants (1 male and 2 females) were excluded due to insufficient PLC data. The final sample, depicted in the pie chart in Figure 41 alongside the age scatter plot and BMI pie chart, comprises 48 participants. Subsequent analysis will focus solely on these 48 participants.

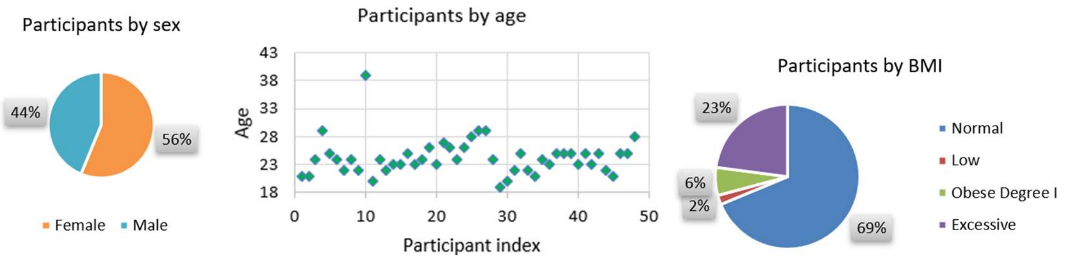

Figure 41 – Left: Pie chart depicting sex distribution. Middle: Scatter plot showing participants' ages. Right: Pie chart illustrating participants' BMI.

From the initial questionnaire many data were retrieved. The Fitzpatrick scale distribution is presented in Figure 42.

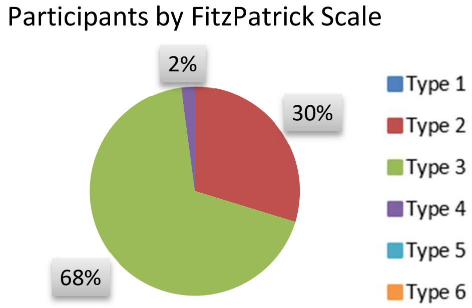

Figure 42 – Distribution of the participants according to their skin tone. Type 1, 5 and 6 are not visible because no participant had this skin type.

Regarding facial hair, all male participants had beards. In terms of makeup, none of the males wore any, while 32% of the females did. Figure 43 shows the intensity of beard and makeup for those who had them.

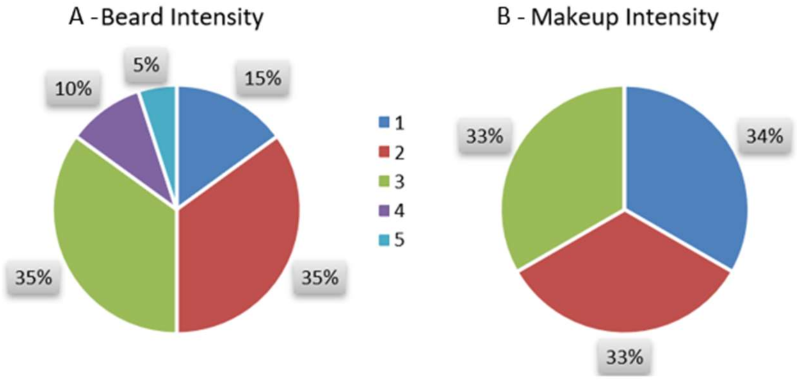

Figure 43 – Beard (A) and make-up (B) intensity distribution among participants. All beard intensities (1-5) had at least one participant, whereas make-up intensities 4 and 5 had no participants, and thus are not displayed in the graph.

Results from the DASS-21, PSWQ-16 and Brief Cope questionnaires are presented in Table 11 to 13 and graphically in the chart of Figure 44.

Table 11 – Percentage distribution of participants across DASS-21 classifications.

Classification	Depression	Anxiety	Stress
Normal	41.67%	52.08%	66.66%
Mild	12.50%	8.33%	12.50%
Moderate	14.58%	14.58%	12.50%
Severe	25.00%	8.34%	4.17%
Extremely severe	6.25%	16.67%	4.17%

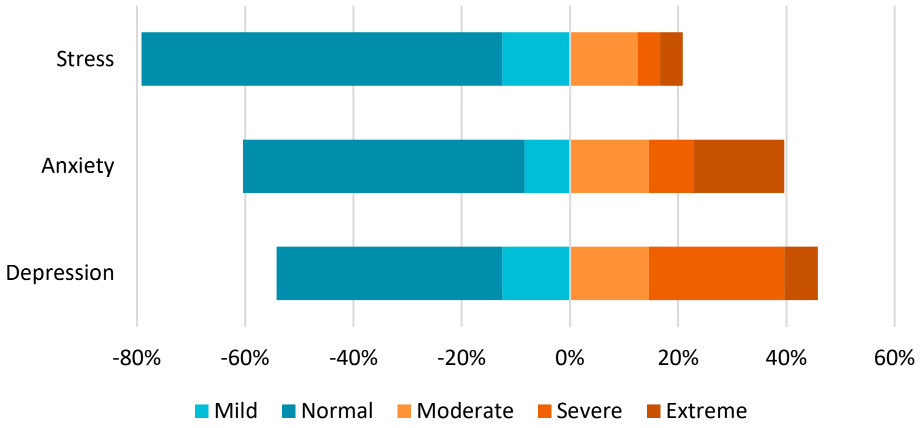

Figure 44 – DASS-21 participants distribution.

Table 12 – Percentage distribution of participants across PSWQ-16 classifications.

Classifications	Worry
Minimal	0.00%
Moderate	66.67%
Considerable	29.17%
Chronic	0.00%

Table 13 – Percentage distribution of participants dominant coping strategies.

Classifications	Dominant coping strategy
Problem focused	68.75%
Emotion focused	25.00%
Coping Avoidance	6.25%

5.2.2 Experimental conditions

The noise level has a mean of 45 dB ± 2 dB for every participant in each light condition. Table 14 provides descriptive statistics for environmental temperature, relative humidity, and light colour, encompassing all participants in both light conditions. Similarly, illuminance results are presented in Table 15. Uniformity across all areas, including the eyes, was 100%.

Table 14 – Descriptive statistics of environmental conditions for both illuminance parameters.

	Temperature (°C)		Relative Humidity (%)		Light Colour (Kelvin)	
Lux	500	300	500	300	500	300
Mean	23.9	24.0	56.0	55.6	3704	3716
Standard deviation	1,6	1,4	4,9	4,8	39,1	21,1

Table 15 – Descriptive statistics of illuminance in lux. Abbreviations: '_5' - 500 lux condition; '_3' - 300 lux condition; 'TA' - Task Area; 'NA' - Neighbourhood Area; 'RE' - Right Eye; 'LE' - Left Eye.

Statistic	TA_5	NA_5	TA_3	NA_3	RE_5	LE_5	RE_3	LE_3
Mean	511	306	270	169	474	478	324	323
Expected mean values	>500	<300	>300	<200	>500	>500	>300	>300
Standard deviation	24	30	12	31	17	23	23	23

In Figure 45, the results for environmental temperature, relative humidity, and light colour classifications are displayed, respectively. Comparisons for each light condition are also shown.

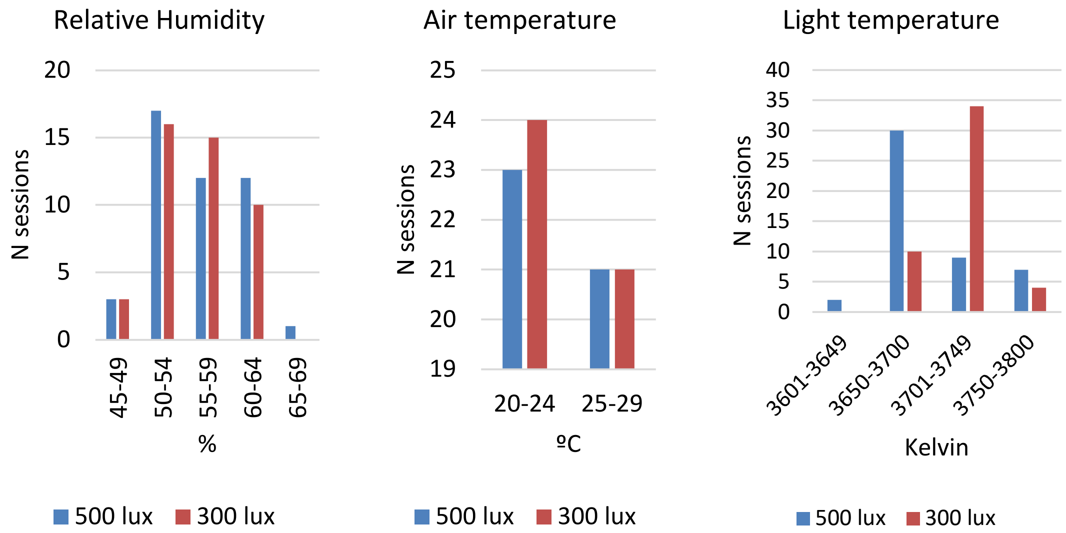

Figure 45 – Comparison by light condition of environmental relative humidity, temperature, and light colour, respectively, grouped by class.

5.2.3 Subjective methods

According to VAS scores, when comparing conditions at 300 lux and 500 lux, 39% of participants felt less stressed at the higher light level, while 50% experienced reduced mental fatigue, and 52% reported less eye strain. Descriptive statistics for VAS scores are displayed in Table 16.

Table 16 – Descriptive statistics of VAS score for all participants.

		Stress			Fatigue			Eye strain		
	Task	Min (mm)	Max (mm)	Mean (mm)	Min (mm)	Max (mm)	Mean (mm)	Min (mm)	Max (mm)	Mean (mm)
500 lux	2-back	0	80	36	0	90	40	0	100	44
	3-back	0	95	50						
	Email	0	80	28						
300 lux	2-back	0	70	32	0	95	45	0	100	50
	3-back	0	95	50						
	Email	0	74	25						

Regarding NASA-TLX, Figure 46 shows the distribution of workload perceived scores for all participants in each task, with light condition comparison. Table 17 displays the scores descriptive statistics. Additionally, 40% of participants felt less workload at 500 lux.

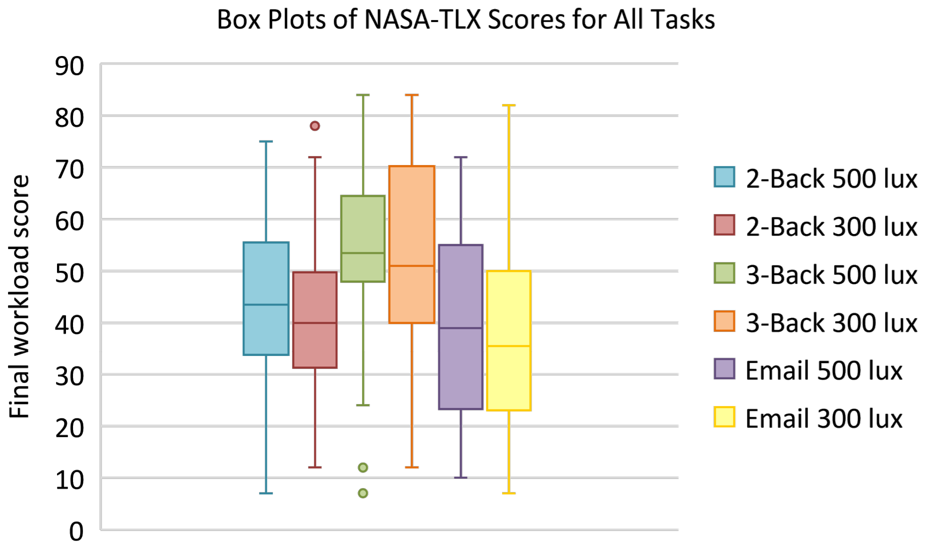

Figure 46 – Scatter plot of perceived workload (NASA-TLX score) across all tasks in both light conditions.

Table 17 – Descriptive statistics of NASA-TLX workload score for all participants.

Illuminance	Task	Min	Max	Mean	Amp
500 lux	2-back	7	75	43	68
	3-back	7	84	53	77
	Email	10	72	40	62
300 lux	2-back	12	78	41	66
	3-back	12	84	53	72
	Email	7	82	37	75

5.2.4 Objective methods

Concerning PLC data, before definition of limits to extract pupil diameter a mean value with standard deviation graph (Figure 47) was constructed for each light condition. After defining the limits, Figures 48 and 49 were generated for each light condition and task, facilitating visual interpretation.

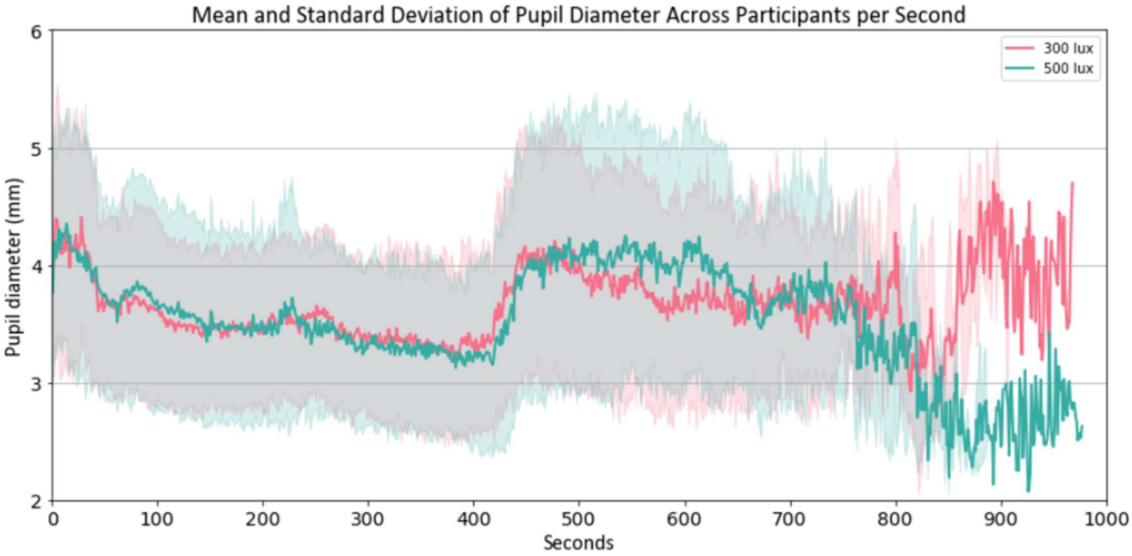

Figure 47 – For each condition line plots of mean values with standard deviation shading are displayed. The mean and standard deviation were calculated for each second.

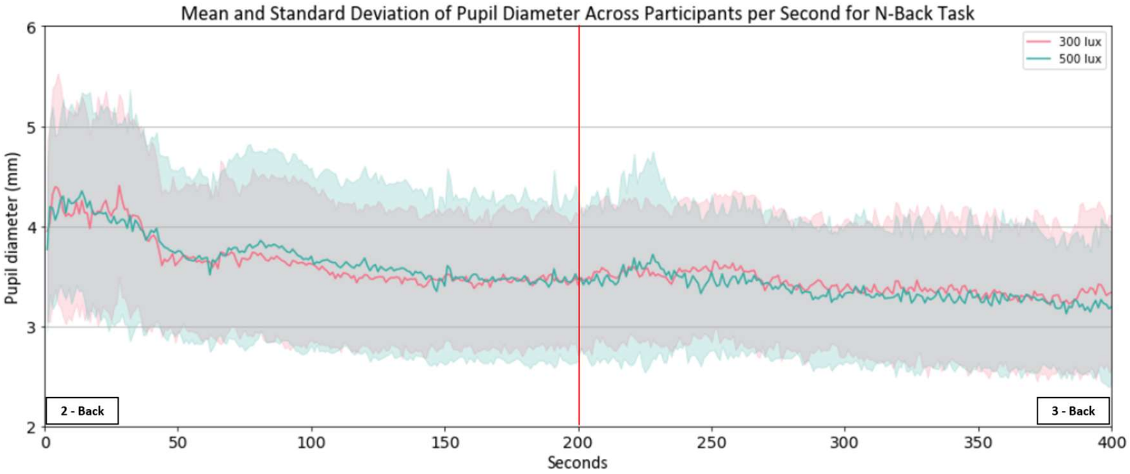

Figure 48 – For each condition in both the N-back tasks line plots of mean values with standard deviation shading are displayed. The mean and standard deviation were calculated for each second, aggregating the average pupil diameter values across different participants over the first 400 seconds. The red vertical line separates 2-Back values from 3-Back values.

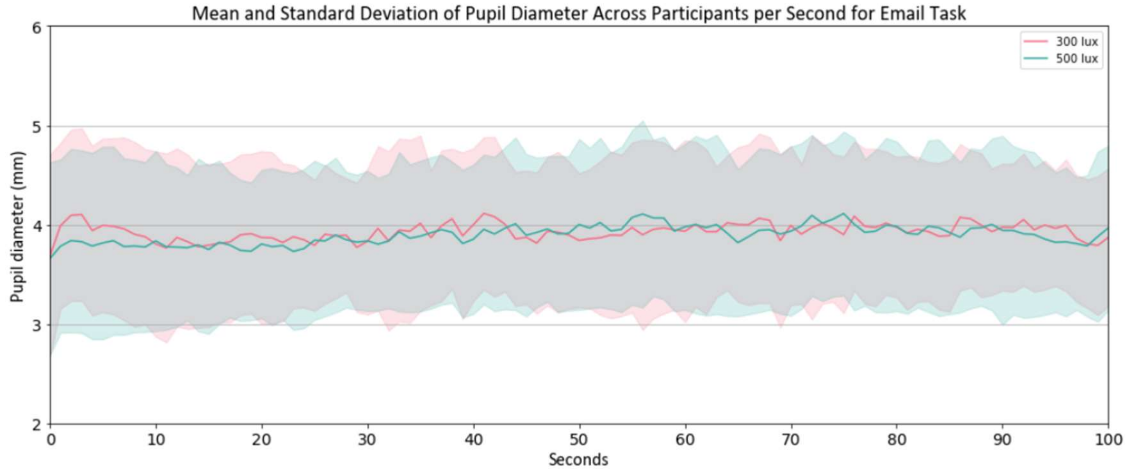

Figure 49 – For each condition in both the email tasks, line plots of mean values with standard deviation shading are displayed. The mean and standard deviation were calculated for each second, aggregating the average pupil diameter values across different participants over the last 100 seconds.

Table 18 summarizes descriptive statistics for pupil diameter across all participants and both light conditions, encompassing the maximum and minimum values of diameters, as well as the mean values for both diameters, variances, and amplitudes. Also, the mean of the five last seconds compared to the first five seconds of PD showed a decrease in pupil of 79.17 % at 300 lux and 75 % at 500 lux.

Table 18 – Descriptive statistics of PLC pupil diameter for all participants.

	Task	Min (mm)	Max (mm)	Mean (mm)	Amp (mm)	Var
500 lux	2-back	2.00	7.94	3.71	2.70	0.27
	3-back	2.00	7.47	3.36	1.56	0.16
	Email	2.01	7.55	3.73	1.88	0.22
300 lux	2-back	2.97	8.00	3.62	2.72	0.28
	3-back	2.97	6.54	3.36	1.62	0.14
	Email	2.97	7.09	3.61	1.96	0.23

Regarding the ECG data, three additional participants were excluded due to insufficient data. For the remaining participants, two scatter plots (Figure 50) were created, displaying the mean HR (bpm) for each light condition of all 45 included participants. Similarly, the average of all participants' emotional means for each light condition is shown in Figure 51. 52.01 % of participants presented initial surprise and fear

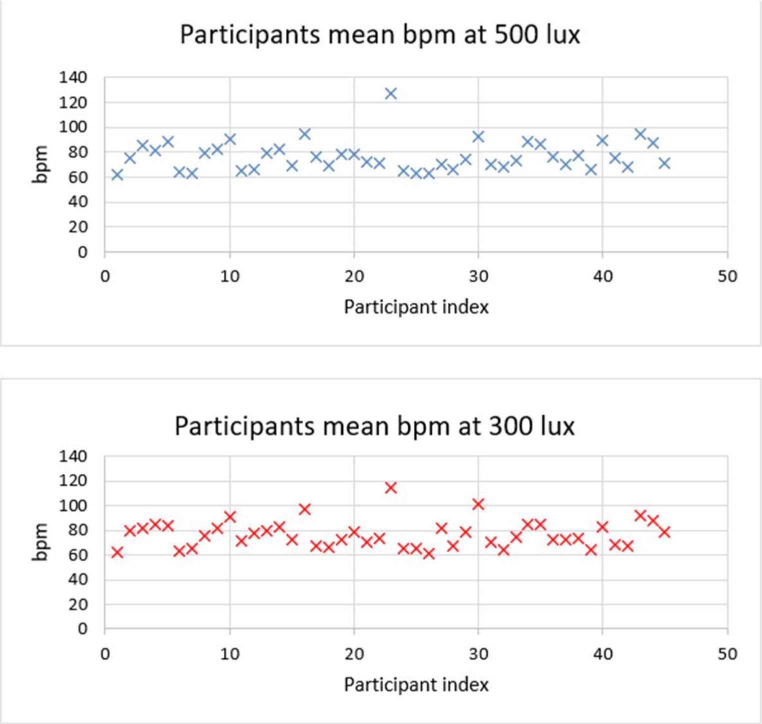

Figure 50 – Heart rate distribution of participants throughout the entire duration of each light condition.

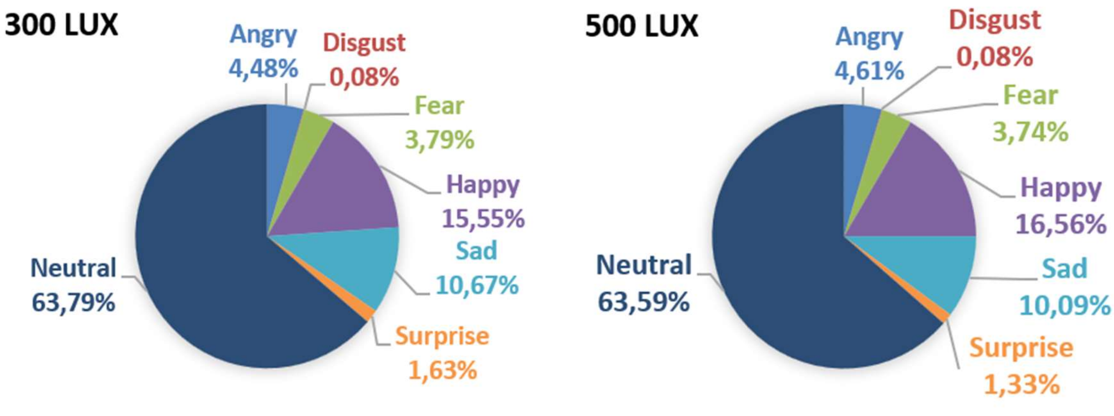

Figure 51 – Emotions mean distribution at each light condition.

In terms of performance measurement, only the performances from N-back tasks were calculated. Several participants did not apply sufficient force on the space key, resulting in incorrect performance recordings of zero. Consequently, 11 participants were excluded from the 500 lux condition and 13 participants were excluded from the 300 lux condition. Figure 52 displays the performance percentages for both light conditions side by side, grouped by class.

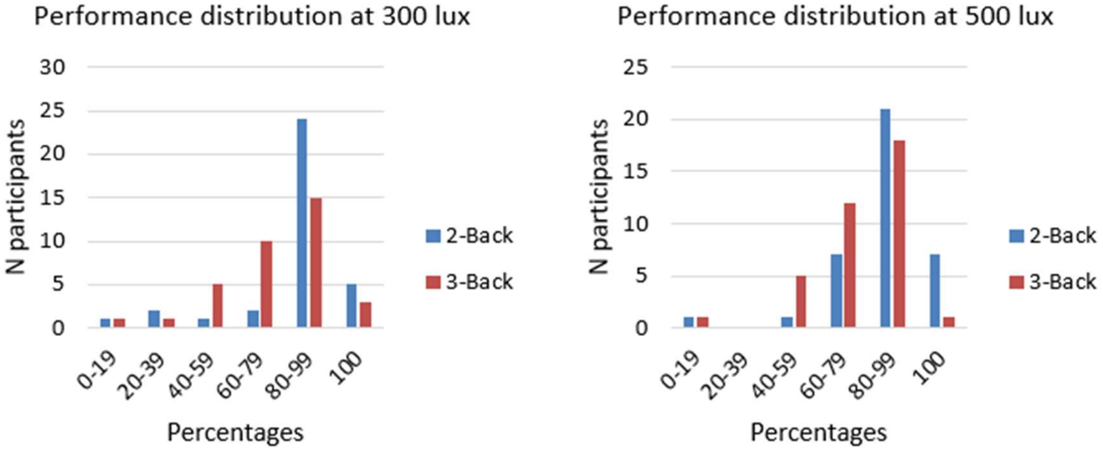

Figure 52 – Distribution of N-back performances by condition.

5.2.5 Statistical analysis

At least one variable among all compared variables did not follow a normal distribution. Therefore, a repeated measures within-subjects ANOVA with Bonferroni correction across three conditions was performed, relying on its established robustness to violations of normality (Blanca *et al.*, 2023). Post-hoc pairwise comparisons were conducted using Tukey's test to adjust for multiple comparisons. These tests were applied to identify differences in the mean and variance of pupil size for each task, as well as in the NASA-TLX score and VAS for stress, under each lighting condition (Table 19). The Tukey pairwise comparisons for both subjective and objective methods can be seen in Figure 53.

Table 19 – Repeated measures ANOVA with Bonferroni correction for all three tasks in each light condition. (PD – Pupil diameter; VAS – Visual Analogue Scale; NASA-TLX – NASA Task Load Index)

Measure	df	F	p-value	F critical
Mean PD 500 lux	2	15.32	0.000	3.09
Variance PD 500 lux		4.48	0.014	
Mean PD 300 lux		8.24	0.001	
Variance PD 300 lux		10.32	0.000	
NASA-TLX 500 lux		18.52	0.000	
NASA-TLX 300 lux		21.04	0.000	
STRESS (VAS) 500 lux		15.72	0.000	
STRESS (VAS) 300 lux		29.15	0.000	

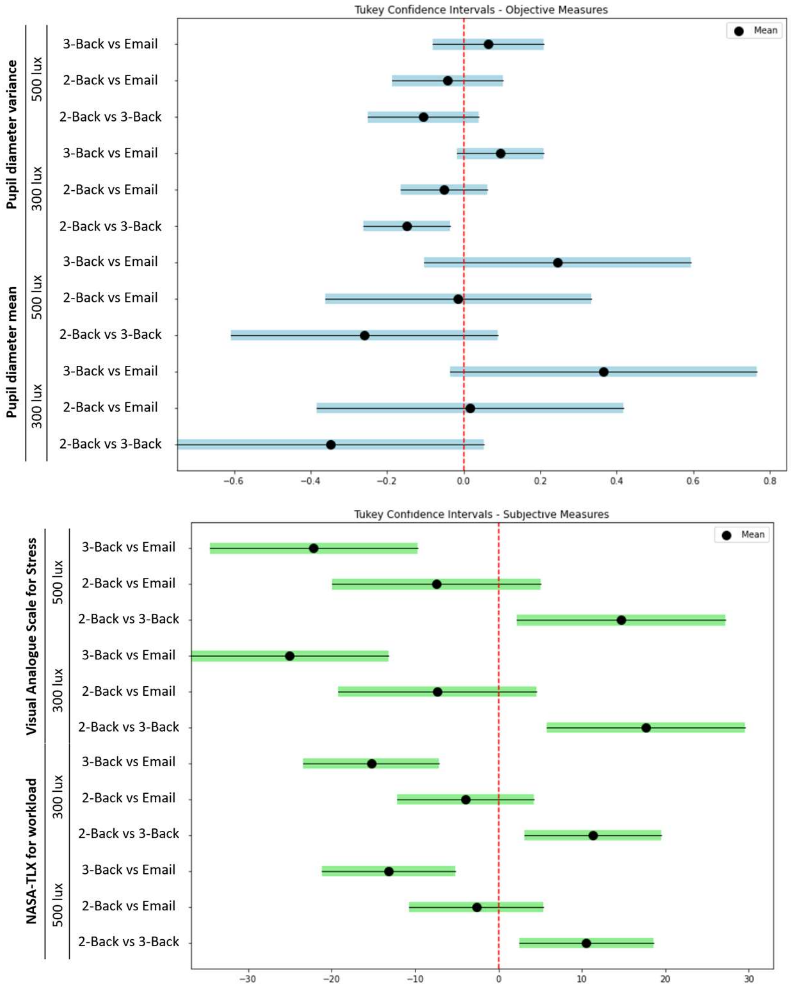

Figure 53 – Tukey confidence intervals for both objective and subjective measures. If an interval does not contain zero, the corresponding means are significantly different.

Since the variables did not follow a normal distribution, a Spearman correlation test was performed to determine age influence on PD and ECG (Table 20). Additionally, Spearman correlation tests were performed for N-Back performance and both methods (subjective and objective) (Table 21).

Table 20 – Spearman correlation values for age and objective measures.

Variable 1	Variable 2	Spearman Correlation value
Age	2-Back mean PD at 500 lux	-0.0276
	3-Back mean PD at 500 lux	-0.0503
	Email mean PD at 500 lux	-0.0706
	2-Back mean PD at 300 lux	-0.0485
	3-Back mean PD at 300 lux	-0.0471
	Email mean PD at 300 lux	-0.0706
	HR mean at 500 lux	0.2851
	HR mean at 300 lux	0.1712

Table 21 – Spearman correlations of N-Back performances with both subjective and objective measurements.

Task Performance	Measures*	Spearman Correlation value
	Mean PD 500 lux	0.046
2 -Back 500 lux	NASA-TLX 500 lux	-0.088
	STRESS (VAS) 500 lux	-0.003
	PD Variance 500 lux	0.373
3-Back 500 lux	NASA-TLX 500 lux	0.063
	STRESS (VAS) 500 lux	0.094
	Minimum PD 300 lux	0.121
2-Back 300 lux	NASA-TLX 300 lux	0.070
	STRESS (VAS) 300 lux	-0.027
	Minimum PD 300 lux	-0.104
3-Back 300 lux	NASA-TLX 300 lux	0.020
	STRESS (VAS) 300 lux	-0.202

*For PD the variable with the higher correlation value was chosen.

5.3 Discussion

This section is structured into four distinct parts. The first segment examines sample characterization and its correlation with the functionality of both physiological equipment's used for data collection. The second part compares environmental findings across the two light conditions. The third segment presents the discussion of the assessment of the determinants of CFPW. Lastly, the fourth part outlines the limitations encountered during the study.

5.3.1 Sample characterization and equipment functionality

The sample characterization showed higher percentages of normal values for depression, anxiety and stress with few extremely severe cases for all (Table 11 and Figure 44). Even though there are few extremely severe cases, they may have a disproportionate impact on descriptive statistics and analyses of correlations or group differences (Osborne and Overbay, 2004). It is crucial to consider these factors when interpreting the study's findings. Regarding worry, no participant showed minimal or chronic values, most presented moderate values. In terms of coping strategies, the majority of participants were problem focused, which involves directly addressing the stressor or problem. This approach is often seen as adaptive and can potentially mitigate the impact of stressors on mental health (Tsaras *et al.*, 2018). Few presented emotions as the main focus and even fewer participants showed avoidance regarding coping strategies. Additionally, the sample has balanced percentage of both sex with a slightly higher number of females (56 %). This diverse sample characterization enhances the generalizability and applicability of the findings across different populations and contexts.

Regarding ECG and emotions exclusions, two participants were dismissed due to the lack of face recognition: one was due to the intensity of his beard, and the other was because their face was positioned away from the camera. Both factors prevented the software from recognizing the necessary points for data collection. Additionally, another participant was excluded due to a complete absence of data, likely caused by either a system malfunction due to overload or an error in renaming the correct folder.

In relation to beard and makeup (Figure 43), these factors did not seem to affect any equipment beyond what was previously explained. Similarly, BMI (Figure 41, right chart) and skin colour (Figure 42) did not appear to affect any equipment results. Only 2% of participants (1 individual) had darker skin, and it was not the darkest type, so no definitive conclusions should be drawn about the equipment's performance across all skin types. Nonetheless, considering all presented results, the PLC equipment can be broadly used. However, for the Mad@work software, an intense beard may impact the results.

5.3.2 Environmental conditions

The study findings indicate consistent noise levels among participants across different light conditions, with a mean of 45 dB ± 2 dB. Environmental conditions such as temperature, relative humidity, and light colour were also meticulously documented. Table 14 details these conditions, displaying descriptive statistics including mean values for each parameter and respective standard deviation.

For environmental temperature, the standard deviation was 1.6 °C and 1.4 °C for 500 and 300 lux, respectively. Relative humidity deviation was 4.9 % and 4.8 % for the respective light conditions. Light colour, measured in Kelvin, showed a standard deviation of 39.1 and 21.1 Kelvin. The standard deviations observed under different lighting conditions are not significant. These minor variations in temperature and relative humidity are well within workplace comfortable conditions (Decreto-Lei n.o 243/86, 1986). Additionally, light colour was always within the neutral conditions range (4000 ± 10% Kelvin) (EDP, 2016). Although the percentage variations of humidity appear notable, they are not substantial enough to significantly affect environments or processes. Liu et al. (2023) concluded that the fluctuations in relative humidity can be justified by the dynamics of the environment during data collection due to human influence.

Table 15 presents illuminance data in lux across different areas and eyes, mean values and standard deviation for each condition (500 lux and 300 lux). The uniformity across all areas, including the eyes, was 100%, showing a homogeneous distribution of light. The mean values for illuminance are mostly consistent with the expected values for all areas in both light conditions. Therefore, any variation in air conditioning, such as temperature or humidity, did not significantly affect the illuminance levels, as expected. Additionally, the results show that both light conditions were consistently applied to all participants.

Figure 45 visually compares environmental conditions (temperature, relative humidity, and light colour) between the two light conditions, illustrating how these factors vary across them. 500 lux presented less relative humidity, equal air temperature and lower light colour than 300 lux. Thus, higher illumination was combined with lower colour temperature and lower illumination with higher colour temperature.

Overall, these detailed measurements provide a comprehensive understanding of the environmental conditions and illuminance levels experienced by participants under varying light conditions, crucial for evaluating their potential impact on study outcomes, referred on the next subchapters.

5.3.3 Determinants of cognitive function and psychological well-being assessment

The determinants of CFPW assessed during this study were fatigue, attention, workload, and stress, which will be further discussed in this order.

In terms of fatigue, subjectively half of the participants felt less fatigued at 300 lux. Similarly, objectively, under the 300 lux condition, participants exhibited higher amplitudes of pupil dilation and smaller mean PD, along with a higher percentage of pupil constriction during the sessions compared to 500 lux (79.17% > 75%). These findings suggest a higher proportion of participants experiencing greater pupil constriction at 300 lux, indicating increased fatigue. The observed pupil constriction aligns with existing literature (Hopstaken *et al.*, 2015; Bafna and Hansen, 2021), which associates pupil response with fatigue augmentation.

These findings indicate that lower illuminance combined with higher colour temperature contributes to increased fatigue among participants, consistent with the findings of a study by Chen et al. (2023). Conversely, research has demonstrated that 500 lux is effective in reducing fatigue (Yu and Akita, 2023), aligning with the results of this study.

For fatigue, objective results were higher than subjective, aligning better with other studies results and findings (Völker, Kirchner and Bock, 2016) which indicates that subjective methods are less reliable, because since the responses are subjective, the results may differ depending on the personal interpretation of the evaluated criteria (Alaimo *et al.*, 2020).

Regarding attention, performance and PD metrics serve as objective measures, complemented by subjective eye strain assessment for comparison. Research consistently shows that eye strain can lead to discomfort and distraction, all of which can impair cognitive functions including attention (Lavie, 2010; Hopstaken *et al.*, 2016). Moreover, eye strain can alter reaction times (Akagi *et al.*, 2019), impacting performance and leading to attentional drift.

Subjectively, 52% of participants reported less eye strain at 500 lux, with a lower mean score of 44 compared to 50 at 300 lux, which corresponds with higher performance observed at 500 lux (Figure 52). Consequently, higher illuminance levels are associated with reduced eye strain, improved performance, and potentially enhanced attention. In terms of PD measurements, Table 21 shows majorly higher correlation values for PD metrics and performance rather than subjective measurements and performance. So, concordant with other studies (Felgueiras *et al.*, 2023; Zhou and Pan, 2023; Payedar-Ardakani *et al.*, 2024) the results suggests that increasing illuminance results in decreased eye strain, improved performance, and potentially higher levels of attention, supported by both subjective and objective measurements. However, objective measures present higher correlation values, presenting better results than subjective methods, aligning with the literature (Fuermaier *et al.*, 2021).

These results point to the practicality of making the lighting environment in workplaces suitable for enhancing cognitive functions and productivity. By matching these findings with means of providing light, corporations can encourage a better health status and increased work efficiency which promote concentration.

For workload and stress assessment, the tasks were designed to progressively increase in difficulty, starting with the 2-Back task, followed by the 3-Back task, and culminating in the highest workload imposed by the writing/email task.

Knowing this, when comparing subjective values for all tasks in both light conditions, Figure 46 shows an increase on workload between 2-Back and 3-Back and a decrease between 3-Back and emails for both conditions. Both light conditions present workload increases in the following order: Email < 2-Back < 3-Back. Table 17 shows the descriptive statistics regarding NASA-TLX. On this table it is possible to see higher means and maximums of workload scores at 500 lux compared to 300 lux. As for stress, subjectively, Table 16 shows higher means in the following order for both light conditions: Email<2-Back<3-Back. All tasks had at least one 0 value appointed so the amplitude corresponds to the maximum level, which are very high (≥70).

However, for objective measures, which are the same for comparison with subjective workload and stress, Figure 48 shows higher PD for 2-Back compared to 3-Back, and Figure 49 shows higher PD for the email task compared to the N-Back tasks. Consistently Table 18 shows an increase PD mean in the following order for 500 lux: 3-Back<2-Back<Email; and the following for 300 lux: 3-Back>Email>2-Back. However, amplitude and PD variance show higher results in both light conditions of the following order: 3-Back<Email<2-Back.

Based on this, there is an observed discrepancy where the email task, expected to elicit higher stress and workload, instead demonstrated lower levels of stress and workload. This can be attributed to variations in individual perception, which may not accurately reflect actual conditions (Matthews, De Winter and Hancock, 2020). In contrast, objective measures consistently showed higher PD means at the email task than the 3-Back task, as expected. For the objective measures switch, the higher results in 2-Back task can be explained by the fact that 2-Back was the first task and an unknown task causing an initial surprise response on participants, followed by familiarisation with task (Fietz *et al.*, 2022; Robison and Garner, 2024). Corroborating, Figure 48 shows a peak at the beginning, causing the 2-Back higher PD results, followed by a stabilization of PD. Additionally, 52.01 % of participants presented higher surprise emotion in the beginning, reverting to neutral which has higher percentages throughout the sessions (Figure 51).

To compare subjective workload and stress to objective measures an ANOVA test was performed. As expected, Table 19 shows that all ANOVA tests yielded a p-value less than the alpha level (0.05), indicating significant differences between all tasks. This suggests that the tasks were distinctly different from each other, confirming the imposed variation levels. Additionally, Figure 53 reveals that comparisons between tasks using subjective methods exhibited more significant differences in means compared to objective measures, reaffirming subjective scales less reliability, that depend on the participant interpretation (Alaimo *et al.*, 2020). Also, for subjective in relation to objective methods, the presented amplitudes in both Table 17 and 18, that show the bigger variation on subjective values by presenting large amplitudes compared to the objective measure.

It was expected for PD to show higher values at 300 lux compared to 500 lux, as the pupil dilates more at lower illuminance levels (Vilotijević and Mathôt, 2023). However, PD presented mostly higher values at 300 lux than at 500 lux throughout the entire session (Figure 47). This visual interpretation is supported by the values presented in Table 18, which show higher means at 500 lux. This can be explained by the increase in attention, workload, and stress at 300 lux, leading to higher PD maximums and amplitudes. Comparing ECG between light conditions nonsignificant difference was observed (Figure 50).

Finally, Table 20 demonstrates a negative correlation between mean PD and age across all tasks and light conditions, consistent with the literature indicating that PD decreases with age (Telek, 2018). Conversely, the table also shows a positive correlation between HR and age for both light conditions, suggesting that age causes an increase in HR, which is also supported by existing research (Vicent and Martínez-Sellés, 2017).

5.3.4 Limitations

Despite asking the same question and providing explanations whenever participants requested, their understanding could still lead to diverse answers. This variation occurs because the subjective dimensions of the NASA-TLX or any VAS questionnaire can be interpreted differently by each participant.

ECG and PLC files varied in size, so an approximate time was defined for each task, which could affect the results. The duration of each task varied among participants due to differences in response speed and the number of key presses during N-back tasks. Additionally, not all participants completed the email writing tasks at the same pace. These variations could influence the results, as the data for all participants was analysed over the same time period.

Another limitation of the study was not altering the order of tasks, which led to higher values of objective measures on the first task that was expected to obtain lower values.

The PLC glasses are not highly adjustable for every face size, resulting in the loss of significant pupil data due to the lack of an ideal position for easy data collection. Although extensions can be helpful at times, they are not always effective.

5.4 Conclusion

Pupillometry can be used in replacement of the gold standard subjective methods to assess workload, stress, fatigue and attention. Subjective responses can vary based on individual interpretation of the evaluated criteria, while objective measures provide more accurate and replicable data. Therefore, it is recommended to use objective methods for a more reliable and precise assessment of the determinants of CFPW.

Regarding environmental conditions, the study indicates that 500 lux and lower light colour is the best lighting combination. This condition is associated with reduced fatigue, lower eye strain, better performance, and potentially higher attention levels among participants. Objective measurements corroborate that higher lighting levels (500 lux) result in less pupil constriction and lower fatigue, while 300 lux lighting, combined with higher colour temperature, tends to increase fatigue and eye strain. Additionally, the 500 lux condition was associated with better management of workload and stress, with participants showing more consistent performance and lower subjective reports of strain. Thus, workplaces aiming to enhance productivity and employees' mental health should prioritize 500 lux lighting levels to promote a more comfortable and efficient environment, effectively managing stress and workload. Thus, workplaces aiming to enhance productivity and employees' mental health should prioritize 500 lux lighting levels to promote a more comfortable and efficient environment.

5.5 Future perspetives

For future research, studies assessing determinants of CFPW using the described methodology in real workplace environments should be conducted. Additionally, implementing eye-tracking equipment in various workplaces could be highly beneficial. This technology could be used to monitor workers' mental health, providing insights that could help reduce stress, fatigue and workload as well as increase attention and improve overall well-being. Moreover, integrating eye-tracking can also enhance companies' productivity by identifying areas where workers may struggle with focus or efficiency, allowing for targeted interventions to improve performance. These advancements would contribute to creating safer, healthier, and more productive work environments.

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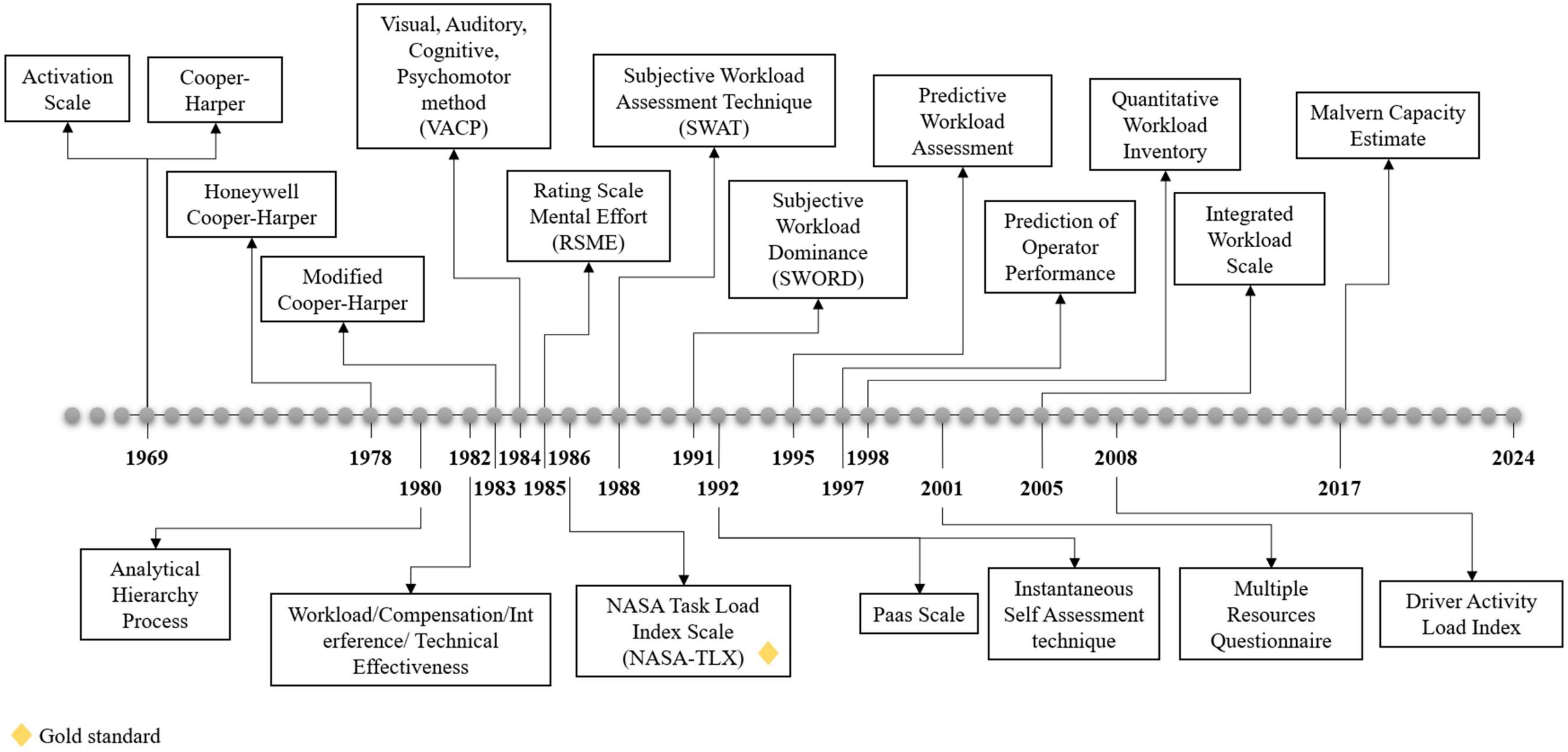
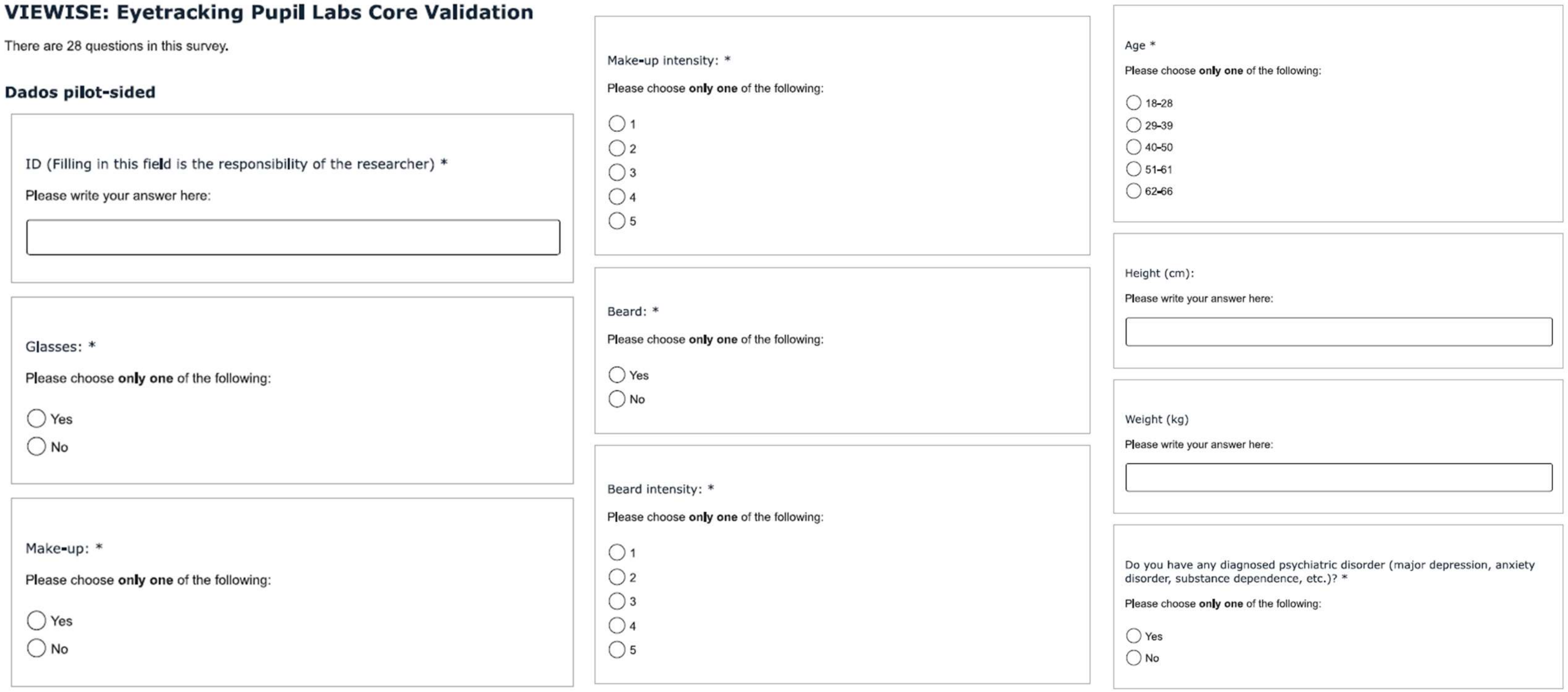
Appendices

Appendix 1 - Chronological Distribution of Workload Scaling.



Appendix 2 – Initial Questionnaire for part 2.



VIEWISE: Eyetracking Pupil Labs Core Validation

There are 28 questions in this survey.

Dados pilot-sided

ID (Filling in this field is the responsibility of the researcher) *

Please write your answer here:

☐

Glasses: *

Please choose **only one** of the following:

○ Yes
○ No

Make-up: *

Please choose **only one** of the following:

○ Yes
○ No

Make-up intensity: *

Please choose **only one** of the following:

○ 1
○ 2
○ 3
○ 4
○ 5

Beard: *

Please choose **only one** of the following:

○ Yes
○ No

Beard intensity: *

Please choose **only one** of the following:

○ 1
○ 2
○ 3
○ 4
○ 5

Age *

Please choose **only one** of the following:

○ 18-28
○ 29-39
○ 40-50
○ 51-61
○ 62-66

Height (cm):

Please write your answer here:

☐

Weight (kg)

Please write your answer here:

☐

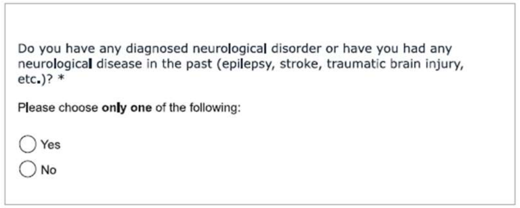
Do you have any diagnosed psychiatric disorder (major depression, anxiety disorder, substance dependence, etc.)? *

Please choose **only one** of the following:

○ Yes
○ No

What diagnosis did you get? *

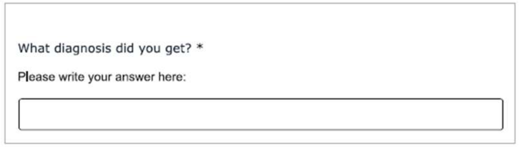
Please write your answer here:



Do you have any diagnosed neurological disorder or have you had any neurological disease in the past (epilepsy, stroke, traumatic brain injury, etc.)? *

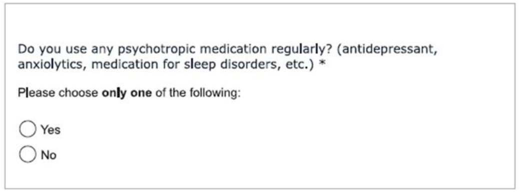
Please choose **only one** of the following:

○ Yes
○ No



What diagnosis did you get? *

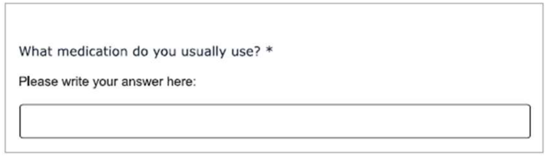
Please write your answer here:



Do you use any psychotropic medication regularly? (antidepressant, anxiolytics, medication for sleep disorders, etc.) *

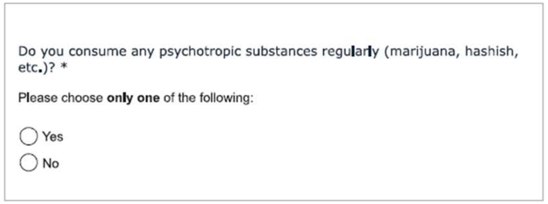
Please choose **only one** of the following:

○ Yes
○ No



What medication do you usually use? *

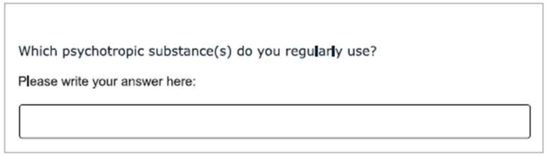
Please write your answer here:



Do you consume any psychotropic substances regularly (marijuana, hashish, etc.)? *

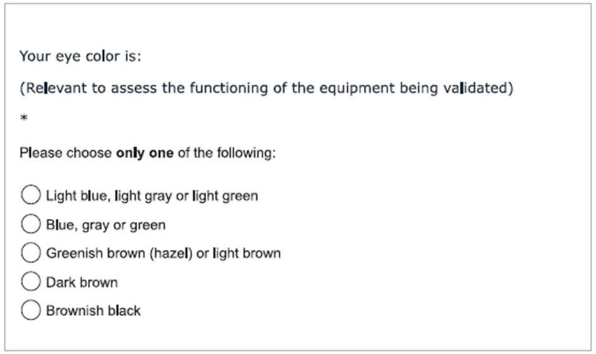
Please choose **only one** of the following:

○ Yes
○ No



Which psychotropic substance(s) do you regularly use?

Please write your answer here:



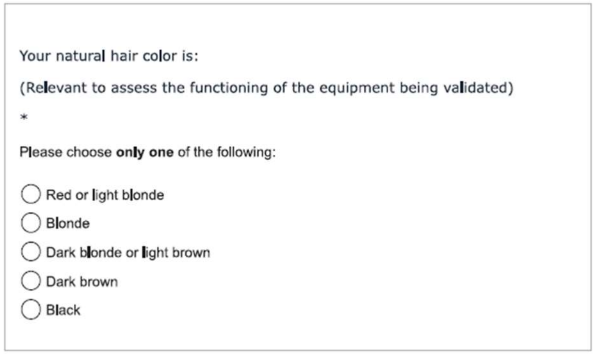
Your eye color is:

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Light blue, light gray or light green
○ Blue, gray or green
○ Greenish brown (hazel) or light brown
○ Dark brown
○ Brownish black



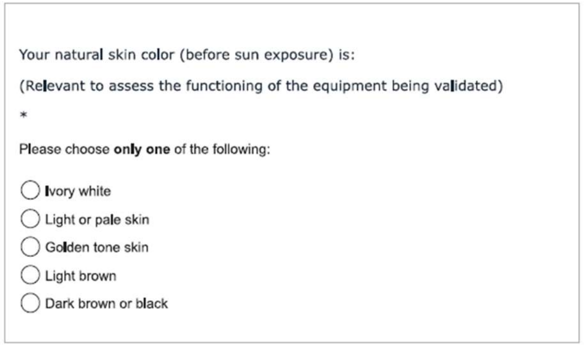
Your natural hair color is:

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Red or light blonde
○ Blonde
○ Dark blonde or light brown
○ Dark brown
○ Black



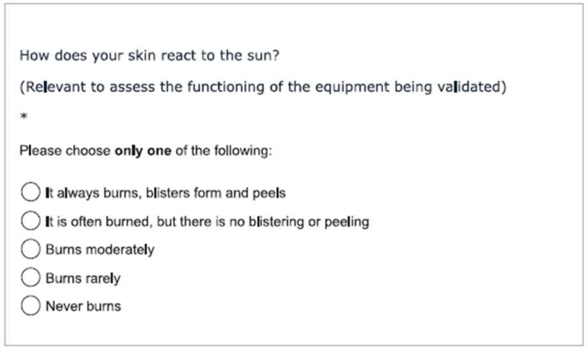
Your natural skin color (before sun exposure) is:

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Ivory white
○ Light or pale skin
○ Golden tone skin
○ Light brown
○ Dark brown or black



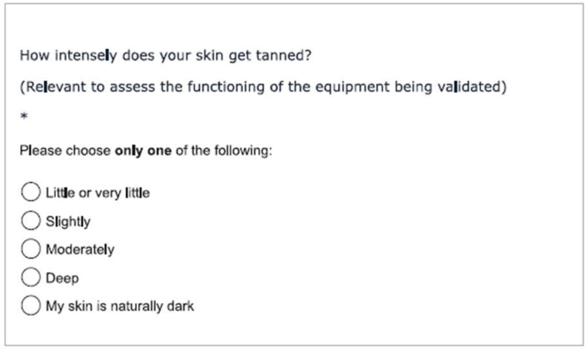
How does your skin react to the sun?

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ It always burns, blisters form and peels
○ It is often burned, but there is no blistering or peeling
○ Burns moderately
○ Burns rarely
○ Never burns



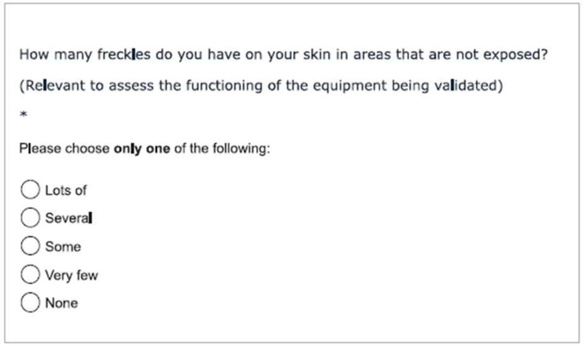
How intensely does your skin get tanned?

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Little or very little
○ Slightly
○ Moderately
○ Deep
○ My skin is naturally dark



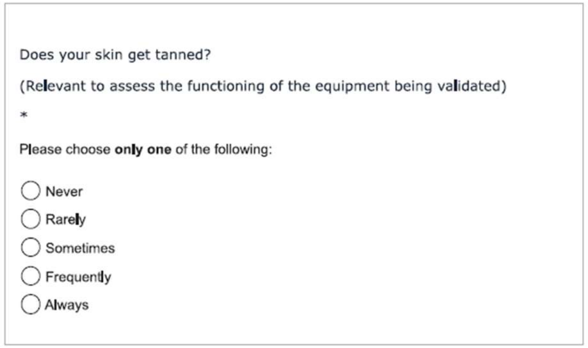
How many freckles do you have on your skin in areas that are not exposed?

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Lots of
○ Several
○ Some
○ Very few
○ None



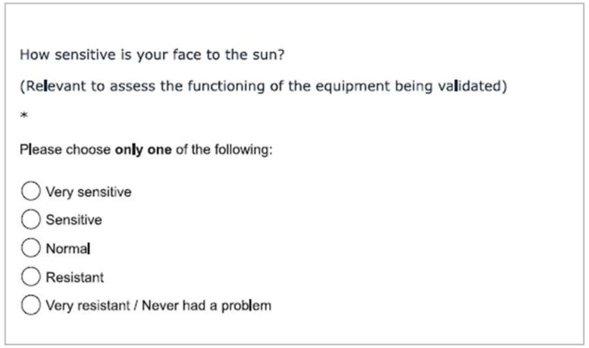
Does your skin get tanned?

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Never
○ Rarely
○ Sometimes
○ Frequently
○ Always



How sensitive is your face to the sun?

(Relevant to assess the functioning of the equipment being validated)

*

Please choose **only one** of the following:

○ Very sensitive
○ Sensitive
○ Normal
○ Resistant
○ Very resistant / Never had a problem

DAS

Please read each of the statements below and mark 0, 1, 2 or 3 to indicate how much each statement applied to you **during the past week**. *There are no right or wrong answers.* Do not take too long to indicate your answer to each statement.

The classification is as follows:

0 - nothing applied to me

1- applied to me a few times

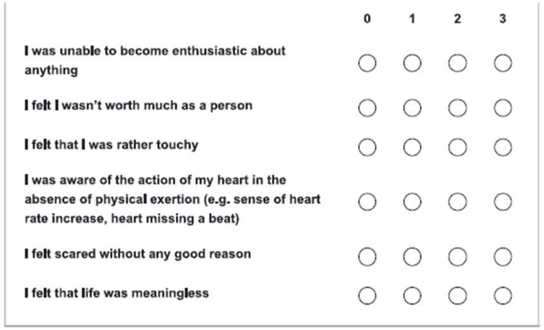
2- applied to me many times

3- applied to me most of the time

*

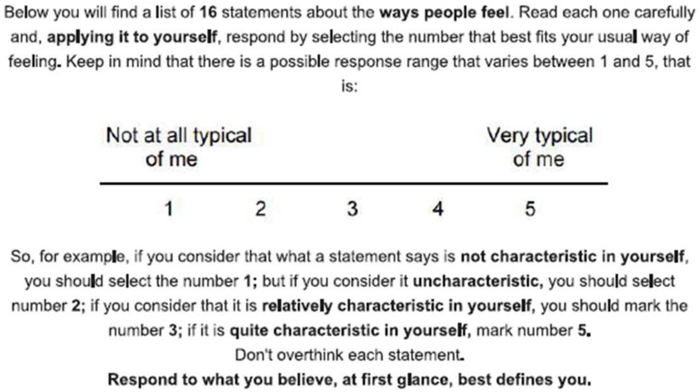
Please choose the appropriate response for each item:

	0	1	2	3
I found it hard to wind down	○	○	○	○
I was aware of dryness of my mouth	○	○	○	○
I couldn't seem to experience any positive feeling at all	○	○	○	○
I experienced breathing difficulty (e.g. excessively rapid breathing, breathlessness in the absence of physical exertion)	○	○	○	○
I found it difficult to work up the initiative to do things	○	○	○	○
I tended to over-react to situations	○	○	○	○
I experienced trembling (e.g. in the hands)	○	○	○	○
I felt that I was using a lot of nervous energy	○	○	○	○
I was worried about situations in which I might panic and make a fool of myself	○	○	○	○
I felt that I had nothing to look forward to	○	○	○	○
I found myself getting agitated	○	○	○	○
I found it difficult to relax	○	○	○	○
I felt down-hearted and blue	○	○	○	○
I was intolerant of anything that kept me from getting on with what I was doing	○	○	○	○
I felt I was close to panic	○	○	○	○



	0	1	2	3
I was unable to become enthusiastic about anything	○	○	○	○
I felt I wasn't worth much as a person	○	○	○	○
I felt that I was rather touchy	○	○	○	○
I was aware of the action of my heart in the absence of physical exertion (e.g. sense of heart rate increase, heart missing a beat)	○	○	○	○
I felt scared without any good reason	○	○	○	○
I felt that life was meaningless	○	○	○	○

PSWQ



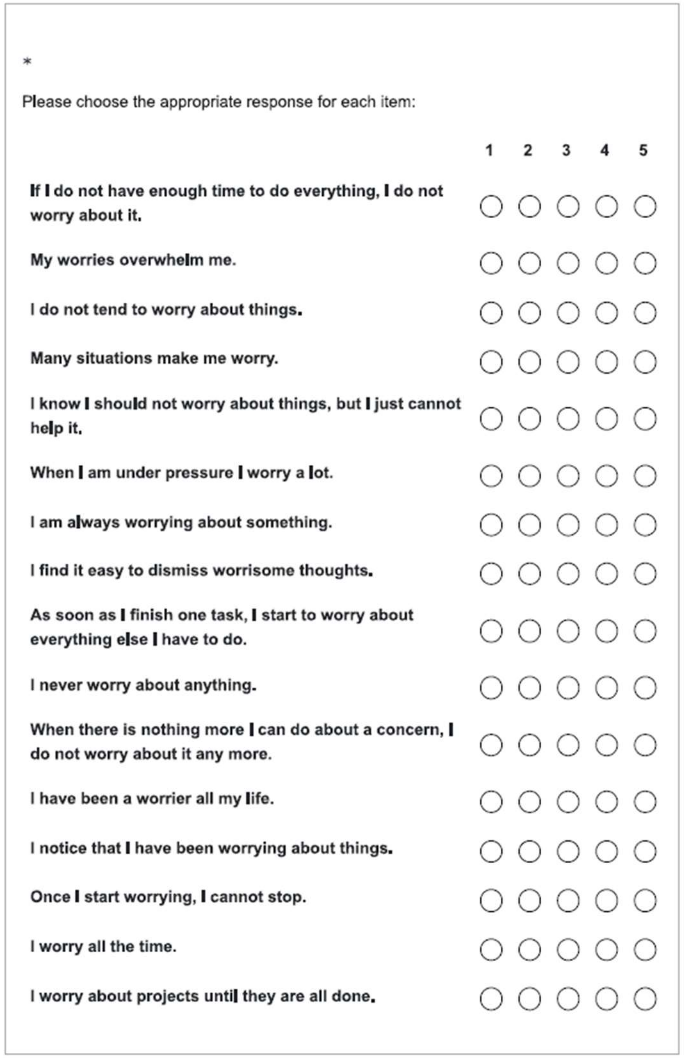
Below you will find a list of **16** statements about the **ways people feel**. Read each one carefully and, **applying it to yourself**, respond by selecting the number that best fits your usual way of feeling. Keep in mind that there is a possible response range that varies between 1 and 5, that is:

Not at all typical of me				Very typical of me
1	2	3	4	5

So, for example, if you consider that what a statement says is **not characteristic in yourself**, you should select the number **1;** but if you consider it **uncharacteristic,** you should select number **2;** if you consider that it is **relatively characteristic in yourself**, you should mark the number **3;** if it is **quite characteristic in yourself,** mark number **5.**

Don't overthink each statement.

Respond to what you believe, at first glance, best defines you.



*

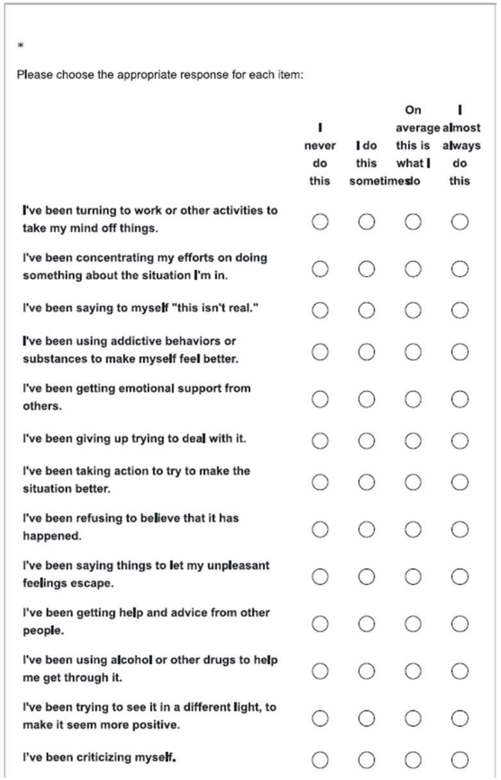
Please choose the appropriate response for each item:

	1	2	3	4	5
If I do not have enough time to do everything, I do not worry about it.	○	○	○	○	○
My worries overwhelm me.	○	○	○	○	○
I do not tend to worry about things.	○	○	○	○	○
Many situations make me worry.	○	○	○	○	○
I know I should not worry about things, but I just cannot help it.	○	○	○	○	○
When I am under pressure I worry a lot.	○	○	○	○	○
I am always worrying about something.	○	○	○	○	○
I find it easy to dismiss worrisome thoughts.	○	○	○	○	○
As soon as I finish one task, I start to worry about everything else I have to do.	○	○	○	○	○
I never worry about anything.	○	○	○	○	○
When there is nothing more I can do about a concern, I do not worry about it any more.	○	○	○	○	○
I have been a worrier all my life.	○	○	○	○	○
I notice that I have been worrying about things.	○	○	○	○	○
Once I start worrying, I cannot stop.	○	○	○	○	○
I worry all the time.	○	○	○	○	○
I worry about projects until they are all done.	○	○	○	○	○

BCope

The following questions focus on how people **deal with stress and problems in life.** There are many ways to try to deal with these types of difficult situations. These items ask what you do to deal with these types of situations. Obviously, different people cope differently, but we are interested in how you deal with these situations.

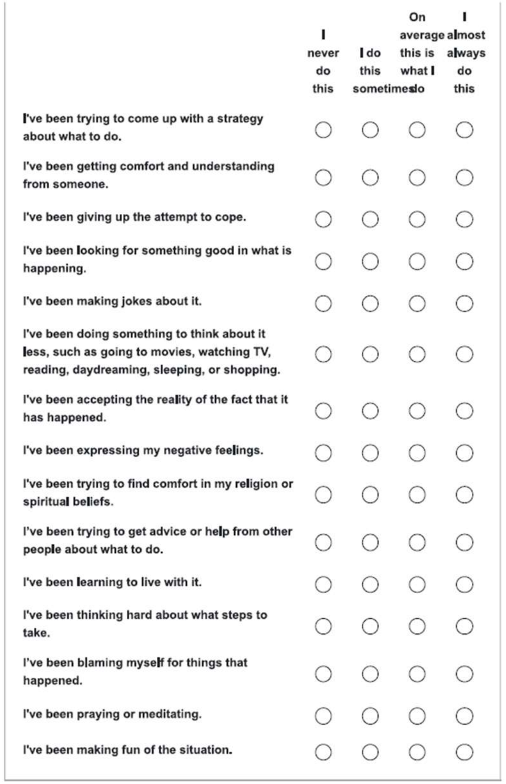
Each item expresses a particular way of dealing with stress or problems in life. We want to know how often **you** adopt the behavior indicated in each item. Select the spaces that best correspond to your behavior, using the answer alternatives presented. There are no right or wrong answers, we ask that you respond as honestly as possible. Answer what it was like for you as truthfully as possible.



*

Please choose the appropriate response for each item:

	I never do this	I do this sometimes	On average this is what I do	I almost always do this
I've been turning to work or other activities to take my mind off things.	○	○	○	○
I've been concentrating my efforts on doing something about the situation I'm in.	○	○	○	○
I've been saying to myself "this isn't real."	○	○	○	○
I've been using addictive behaviors or substances to make myself feel better.	○	○	○	○
I've been getting emotional support from others.	○	○	○	○
I've been giving up trying to deal with it.	○	○	○	○
I've been taking action to try to make the situation better.	○	○	○	○
I've been refusing to believe that it has happened.	○	○	○	○
I've been saying things to let my unpleasant feelings escape.	○	○	○	○
I've been getting help and advice from other people.	○	○	○	○
I've been using alcohol or other drugs to help me get through it.	○	○	○	○
I've been trying to see it in a different light, to make it seem more positive.	○	○	○	○
I've been criticizing myself.	○	○	○	○



	I never do this	I do this sometimes	On average this is what I do	I almost always do this
I've been trying to come up with a strategy about what to do.	○	○	○	○
I've been getting comfort and understanding from someone.	○	○	○	○
I've been giving up the attempt to cope.	○	○	○	○
I've been looking for something good in what is happening.	○	○	○	○
I've been making jokes about it.	○	○	○	○
I've been doing something to think about it less, such as going to movies, watching TV, reading, daydreaming, sleeping, or shopping.	○	○	○	○
I've been accepting the reality of the fact that it has happened.	○	○	○	○
I've been expressing my negative feelings.	○	○	○	○
I've been trying to find comfort in my religion or spiritual beliefs.	○	○	○	○
I've been trying to get advice or help from other people about what to do.	○	○	○	○
I've been learning to live with it.	○	○	○	○
I've been thinking hard about what steps to take.	○	○	○	○
I've been blaming myself for things that happened.	○	○	○	○
I've been praying or meditating.	○	○	○	○
I've been making fun of the situation.	○	○	○	○

Submit your survey.
Thank you for completing this survey.