WORKINGAGE

Smart Working Environments for All Ages

D2.2 Analysis of Available and Suitable Sensors

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 826232.

WP2 – User Centric Design

D2.2 – Analysis of Available and Suitable Sensors

Project number:	826232
Project acronym:	WorkingAge
Project title:	Smart Working Environments for All Ages
Author(s):	Gianluca Borghini, Vincenzo Ronca, Pietro Aricò, Fabio Babiloni, Konstantinos Kentrotis, Julia Czerniak, Vera Rick, Hesam Sagha, Caroline Morisot-Pagnon, Tian Xu, Roberto Tedesco, Basam Musleh, Alberto Navarro, Hatice Gunes, Tian Xu
Partners contributed:	BS, ITCL, EXO, UCAM, POLIMI, RWTH, TPZ, AUD, INTRAS, TMA, GC
Delivery date:	M6 (July 2019)
Document date:	04/12/20195
Version:	3
Revision:	3
Deliverable type:	Report
Remarks:	First submission M6, Second submission M11
Status:	⦿ PU (Public) ○ PP Restricted to other programme participants (including the Commission Services) ○ Restricted to a group specified by the consortium (including the Commission Services) (please specify the group) ○ Confidential, only for members of the consortium (including the Commission Services

Document Revision Log

VERSION	REVISION	DATE	DESCRIPTION	AUTHOR
1	0	28/03/2019	TOC and first version	Gianluca Borghini, Vincenzo Ronca, Pietro Aricò, Fabio Babiloni,
1	1	24/05/2019	Voice Analysis	Hesam Sagha
1	2	29/05/2019	Interview and Eye-Tracking	Julia Czerniak, Vera Rick
1	3	03/06/2019	Location Sensors	Caroline Morisot-Pagnon
1	4	03/06/2019	Facial Expression	Tian Xu
1	5	03/06/2019	Body Posture	Basam Musleh Lancis
1	6	06/06/2019	Voice Analysis	Roberto Tedesco
1	7	11/06/2019	Gesture Recognition	Konstantinos Kentrotis
1	8	12/06/2019	Integration of the partners' contribution and general revision	Gianluca Borghini, Vincenzo Ronca
1	9	14/06/2019	Technology selection survey report	Vera Rick
1	10	25/06/2019	Questionnaire	Raquel Losada Durán
2	0	28/06/2019	Integration of the remaining contributions and document review	Gianluca Borghini, Vincenzo Ronca
2	1	24/07/2019	Partner reviews integrations, inputs from Consortium Meeting	Gianluca Borghini, Vincenzo Ronca
2	2	26/07/2019	Final review and formatting before submission	Marteyn van Gasteren
3	0	05/08/2019	Repaired reference on p.53, section 4	Marteyn van Gasteren
3	1	24/10/2019	Electromyography	Vera Rick
3	2	11/11/2019	Formatting, minor corrections	Marteyn van Gasteren
3	3	05/12/2019	Revision after the 1st Project Review	Vincenzo Ronca, Gialuca Borghini, Roberto Tedesco, Vera Rick, Marteyn van Gasteren

Acronyms and Terminology

The following table reports the acronyms used in this deliverable.

Term	Definition
ANS	Autonomic Nervous System
BOLD	Blood Oxygen Level Dependent
CNS	Central Nervous System
CNN	Convolutional Neural Network
CO_2	Carbon Dioxide
ECG	ElectroCardioGraphy/ElectroCardioGram
EEG	ElectroEncephaloGraphy/ElectroEncephaloGram
EMG	ElectroMioGraphy
EOG	ElectroOculoGraphy/ ElectroOculoGram
ERD	Event Related Desynchronization
ERP	Event Related Potential
ERS	EventRelated Synchronization
fMRI	functional Magnetic Resonance Imaging
fNIR	functional Near-InfraRed
fNIRs	functional Near-InfraRed spectroscopy
FOS	Fast Optical Signal
GAS	General Adaptation Syndrome
GSR	Galvanic Skin Response
HCI	Human Computer Interaction
HF	Human Factors
HMI	Human Machine Interface
HP	Human Performance
HPE	Human Performance Envelope
HRV	Heart Rate Variability
LF	Low Frequency
MEG	MagnetoEncephaloGraphy/MagnetoEncephaloGram
OWAS	Ovako Working Analysis System
PFC	Pre-Frontal Cortex
PNS	Parasympathetic Nervous System
PPC	Posterior Parietal Cortex
PSAP	Public Safety Answering Point
PVT	Psychomotor Vigilance Task
RH	Relative Humidity
RULA	Rapid Upper Limb Assessment
REBA	Rapid Entire Body Assessment
SAM	Sympathetic Adrenal Medullary

Term	Definition
SC	Skin Conductance
SCL	Skin Conductance Level
SCR	Skin Conductance Response
SNS	Sympathetic Nervous System
VHF	Very High Frequency
VLF	Very Low Frequency
WA	WorkingAge

Executive Summary

This document provides the review and analysis of the sensors and technologies which will be employed throughout the experiments of the WorkingAge (WA) project. In particular, detailed descriptions of the sensors and systems for collecting user's subjective (e.g. interview, questionnaire), behavioural (e.g. user motion), and neurophysiological (e.g. brain activity) data during the *In-Lab* and *In-Company* tests are reported. In addition, hypothesis regarding the final setup of the sensors for everyday use in realistic settings has been proposed taking into account the requirements to be as less invasive and unobtrusive as possible, easy to use, and comfortable.

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1 Introduction

Problems concerning the interaction between human and automation have been identified and studied since the 80s [1] and have been reported in the specialized human factor literature. The implementation of adaptive solutions depending on the user's mental and emotional state can then help and support the user itself in dealing with high demanding and stressful events. The perspectives and research trends in prominent areas of neuroergonomics were initially surveyed by Parasuraman [2] who summarized how neuroimaging studies could help in assessing the user's mental and emotional state in complex tasks, trigger adaptive solutions and provide severely disabled users with new communication channels. The WorkingAge (WA) project intends to use sensors and combination of biosignals to monitor the workers' cognitive and emotional state and identify appropriate actions to support their work and daily life with the aim to improve their working conditions and life style. In this regard, several experiments have been planned throughout the WA project, starting from controlled conditions (*In-Lab*) to real working settings and situations (*In-Company*). The final goal of the WA project is to develop a tool (called *WA Tool*) capable to be employed within realistic working and life conditions without affecting such conditions and settings. As a consequence, the final set of sensors of the *WA Tool* must not interfere with the workers and provide reliable information for the worker's mental and emotional states. In fact, measuring physiological signals in ecological environments, and in general during everyday activity, is more difficult than in a rigorous laboratory environment. First, the physiological responses caused by mental stress can be masked by variations due to physical activity [3]. For example, people may have higher heart rate when standing than when sitting. Heart rate may also increase when people are mentally stressed. Hence, using heart rate alone as an indicator to detect mental stress may lead to misclassifications. Second, signal artefacts caused by motion, electrode placement, or respiratory movement affect the accuracy of measured recordings. Third, it is also difficult to determine the ground truth of a user's stress level when labelling training data in mobile environment. These factors increase the difficulty of developing a pervasive user's mental and emotional states detection application for everyday use. For such a reason, different kinds of sensors and technologies will be employed in the WA project in order to identify those more capable to address and satisfy the requirements for everyday usage in working conditions. In particular, subjective, behavioural, environmental, and neurophysiological data will be collected and analysed to define the proper Ontology to deploy the most appropriate Human-Computer-Interaction (HCI) solutions to support the workers while dealing with the working activities and finally improve their life conditions. The deliverable is intended to provide detailed descriptions of the potential technology solutions and criteria for the development of the WA Tool.

2 Sensors

2.1 Biosignal Sensors

In the WA project different types of stress/strain (cognitive, visual, auditory, and physical) will be represented in several modules using different sensors and the necessary technology to interpret them. Thus, mental workload, stress, and emotion will describe the "internal" perception of the user of the external stressors as well as the internal, endogenous activities. The "internal" state of the person is somewhat multidimensional, therefore a reasonable combination of bio variables, thus sensors, is necessary for reliable measurement of such stress\strain conditions.

2.1.1 Sensors for mental workload assessment: Electroencephalogram (EEG) and Electrooculogram (EOG)

Almost a century ago (1924), the German physiologist and psychiatrist Hans Berger (1873-1941) was able to record human brain electrical activity through two electrodes placed on the scalp, applying for the first time techniques investigated some years before by his colleagues on animals. This technique, that Berger named "Electroencephalography" (EEG), is considered as "one of the most surprising, remarkable, and momentous developments in the history of clinical neurology". Nowadays, EEG is actually one of the most common and used techniques of neuroimaging, since if compared with other techniques such as functional Magnetic Resonance Imaging (fMRI), Magnetoencelography (MEG) and functional Near-InfraRed spectroscopy (fNIRS), it is able to ensure at the same time great temporal and potentially good spatial resolution (with a high number of electrodes), and it is relatively cheap and portable [4]. For such a reason, during the last decades EEG has got out of hospital doors, becoming not only a reliable monitoring system for healthcare [5] but also a powerful and versatile tool for investigating human brain physiology, cognition and behaviour [6], [7]. Because of the increasing interest and demand of such technology, and thanks to the fast progresses of micro- and nano-electronic industry, biomedical devices manufacturers have been able to drastically reduce the dimensions of EEG devices. Therefore, if in the 60's an EEG device required a room and meters of cables to be hosted, modern EEG devices are large no more than a smartphone and equipped with storage supports, long-life batteries and wireless communication. These great improvements are at the basis of the recent successes of cognitive and behavioural neuroscience research, since it is now possible to investigate human brain physiological dynamics while working or performing everydayness activities, such as driving the car [8]–[10] or piloting an aircraft [11]–[13], working in control rooms [14]–[17], watching the TV [18], [19], doing sport [20], eating [21], listening music [22], [23] or smelling fragrances [24], [25]. The EEG devices are now wearable and they are considered the key tool to bring research about Brain-Computer Interfaces (BCI, i.e. those system aimed to adapt the objects behaviour on the basis of current human mental states) from the laboratory to the applicative fields [26], [27]. In this context, several prototypes of EEG-based BCIs have been already validated in real settings [28], [29], however, a still present issue limiting the development and employment of such technologies is the easiness to use and the acceptability by the user. In fact, despite the great improvements in terms of EEG device sizes and features, the quality and reliability of this technology still relies on recording brain signals through metallic sensors to be applied over the rubbed scalp and by adapting impedances through gels or other conductive substances. More in detail, EEG electrodes are produced with the shape of a cup, disc or needle, and are usually made of Silver (Ag) and Silver chloride (AgCl) [30]. Because Ag is a slightly soluble salt, AgCl quickly saturates and comes to equilibrium. Therefore, Ag is a good metal for metallic skin-surface electrodes [31]. Before putting the electrodes over the scalp, it is necessary to rub scalp skin with pastes or alcohol solutions, in order to remove all the substances and any kind of impurity generally present over the scalp epidermis. Then, traditional Ag/AgCl electrodes require electrolyte gel that facilitates the transduction of the ionic currents between the skin and the electrode. Furthermore, the electrode-skin impedance must be controlled and adapted to achieve acceptable low values, typically 5 ÷ 20 KΩ [32], [33]. These are mainly manual actions that require technicians with expertise in EEG recordings. Another remarkable inconvenience is the annoyance caused to the subject under test. For instance, the abrasive paste and the electrolyte gel, despite being minimally invasive and barely harmful, are sticky products that make the hair and scalp wet and dirty. Also, the time needed to adapt the impedance can last long. The use of a massive electrolyte to speed up the impedance adaptation could cause electrical bridges between electrodes, thus being counterproductive. Last but not least, once acceptable impedances values have been achieved, the following issue will be gel drying, thus causing degradation of its conductive properties. For example, Lin and colleagues [34] measured an impedance deterioration of wet electrodes from 5 to 15 kΩ within 5 hours after gel application. Many of these problems can be minimized by using dry electrode systems [35], therefore the research about EEG dry electrodes, started during the nineties [36], [37], is recently living a very fertile period. Let us think that some years ago practical dry electrodes have been identified as one of the two disruptive technologies in BCI research [38], [39]. Recent studies produced a wide variety of EEG electrode concepts based on dry technology, including silicone conductive rubber [40], comb-like and multi-pin electrodes [41], [42], gold-plated electrodes [38], [43], bristle-type electrodes [44], and foam-based sensors [34]. In general, all these solutions could be categorized into spiky, capacitive/non-contact or other heterogeneous types of contact [45]:

- *Spiky Contact*: in this solution, the electrode surface consists of linear or circular array of spikes that directly come into direct contact with the scalp.

- *Capacitive/Non-contact*: since the absence of impedance adaptation substances could make the skin-electrode contact instable over time, some researchers coped with this difficulty by avoiding physical contact with the scalp (there is a small dielectric between the skin and the electrode itself), but at the cost of an extraordinary increase of electrode impedance.

- *Others*: other heterogeneous approaches in terms of materials, such as foams or solid gels.

In addition, because of their intrinsic higher impedance, if compared with traditional wet electrodes, a complementary solution could be to on-site amplify (i.e. just over the electrode, and upstream the cable toward the device amplifier) the signal with ultra-high input impedance amplifiers (the so-called "active electrodes"). Several attempts are already present in literature about the comparison and validation of these innovative electrodes [43], [46]: there is the common opinion that wet electrodes are still considered the gold standard [43], [45]. It is important to take into account that low-cost devices (i.e. few hundred euros, such as Emotiv, EPOC, or Neurosky MindWave) are still far from being reliable for applications other than gaming and playful activities in general [47], [48]. In this context, Di Flumeri et al. [49] provided a comprehensive comparison between three different types of dry EEG electrodes (Figure 1), among them and with respect to wet electrodes. The wet electrodes consisted in traditional Ag/AgCl ring-shaped electrodes, while the three dry types consisted in:

- Active gold-coated single pin electrode;

- Hybrid (capacitive/conductive) multiple-spikes based electrode;

- Passive solid-gel based electrode.

The three different solutions of EEG dry electrodes have been selected in order to provide a comprehensive state-of-art contribute. In fact, all the electrodes employed within this experiment (a) have been recently produced by leading companies of this domain, (b) are both passive and active, and (c) provide three different types in terms of material and electrode shape.

2.1.1.1 Traditional Wet Ag/AgCl electrodes (Wet)

The wet electrodes employed are traditionally ring-shaped Ag/AgCl electrodes (electrode 'a' in Figure 1) and connected through silver wires to the amplifier. They will be hereinafter labelled "Wet".

2.1.1.2 Active Dry single gold pin-based electrodes (BP Gold)

In this case, the electrodes consisted in a gold-coated single pin with the shape of a mushroom (electrode 'b' in Figure 1). They are produced in 3 different lengths (10, 12 and 14 mm) to be chosen depending on the scalp area (e.g. frontal or parietal area) and hair-length. The signal is amplified just after the electrode (gain factor = 1, Input impedance > 200 MΩ). These electrodes, named actiCAP Xpress QuickBits, are produced by BrainProducts GmbH (Germany). They will be hereinafter labelled "BP Gold".

2.1.1.3 Hybrid Dry multiple spikes-based electrodes (Quasar)

In this case, the electrodes consisted in hybrid biosensors using a combination of high impedance resistive and capacitive contact to the scalp. Electrical contact is made through two rings of spikes (electrode 'c' in Figure 1), with a total diameter of about 3 (cm). The amplifier electronics are shielded and mounted immediately behind the electrode (Input impedance > 10 (GΩ)) in order to limit interference caused by external signals. They are produced by Quasar Inc. (California, USA). They will be hereinafter labelled "Quasar".

2.1.1.4 Passive Dry solid-gel based electrodes (BP Solid)

In this case, the electrodes consisted in a cone made of a hygroscopic solid gel (electrode 'd' in Figure 1). They have to be kept immersed in a saline solution for some minutes before the experiments to hydrate the electrodes, and then their characteristics remain stable up to 8 hours. They are a prototype (thus still not available on the market) produced by BrainProducts GmbH (Germany). They will be hereinafter labelled "BP Solid".

Figure 1. Representative pictures and names of the compared electrodes.

The work published by Di Flumeri et al. [49] demonstrated how the most recent dry electrodes solutions revealed very high level of maturity, both in terms of reliability (i.e. signal quality) and usability. Also, regarding the aspects related to usability, the dry electrodes reduce drastically the time necessary to plug and set up the system: the time of montage of the three dry electrodes were all significantly lower than that one of wet electrodes (
Figure 2).

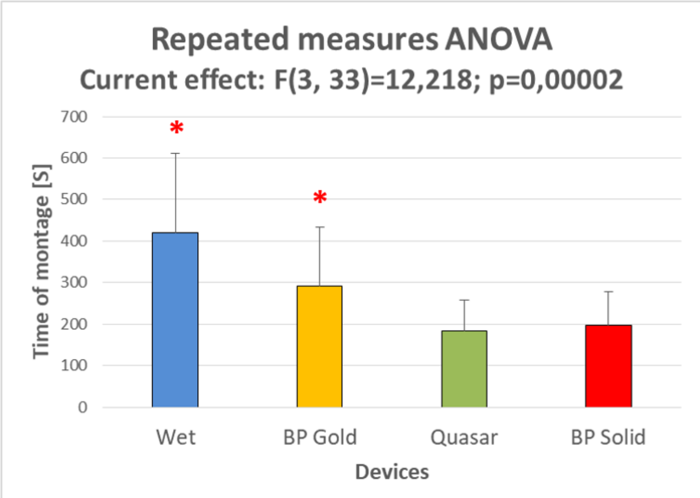

Figure 2. The bar graph represents the mean and the standard deviation of the times of montage of each device. The red asterisks indicate the samples significantly (p <0.05) different from the other ones, as demonstrated by the Duncan's post-hoc tests.

Finally, it is a common experience that when a particular task involves the use of visual attention, the subject becomes more concentrated and the time spent with the eye closed decreases, that is the eyeblinks frequency decreases [50]. Researchers have investigated whether such phenomena could lead to valid indications about the experienced mental workload while dealing with tasks requiring high visual attention, such as car driving. As a result, eye blink data has been collected in highly realistic settings of driving and different parameters characterising of the eye blinks, such as the Blink Rate (BR), the Blink Duration (BD), and the Blink Latency (BL) have been analysed and used as workload measures in a series of studies [51]–[53]. Results in the literature suggested that both the blink rate and blink duration decrease with increases in task demands, and they have been found to significantly decrease during high load segments of missions [54], [55]. The Electrooculogram (EOG) signal is derived from the polarization potential, also known as the Corneal-Retinal Potential (CRP), generated within the eyeball by the metabolically active retinal epithelium [56]. The CRP is produced by means of hyper-polarizations and de-polarizations of the nervous cells in the retina. The EOG signal can be acquired through electrodes placed over the eyes, specifically the Horizontal (H) and the Vertical (V) EOG channels [57] or alternatively using camera focusing on the eyes. Please, see paragraph 2.1.3.2.1 for more details about the EOG.

2.1.2 Sensors for emotional and stress assessment: Electrocardiogram (ECG), Galvanic Skin Response (GSR), and Skin Temperature (ST)

All the scientific literature agrees on the fact that, when the emotional state of a person changes, the human body reacts. Thus, the heart flutters or drops; palms sweat; muscles tense and relax; faces blush or smile. We note these reactions in ourselves, and make inferences about the emotional life of others based on visible bodily responses. William James (1890) called these phenomena the "coarser emotions: fear, rage, grief, love, in which everyone recognizes a strong organic reverberation." In the late 19th and early 20th centuries, when W. James and C. Lange were speculating about the basis of affective life, emotion's "organic reverberation" was not easy to assess in a precise, quantitative way. In 1958, J. Lacey could confidently state: "Such measures as skin resistance, heart rate, blood pressure, blood flow, skin temperature, blood-oxygen saturation, gastric motility, pupillary diameter, muscle tension, and other variables have been shown to be remarkably sensitive and responsive measures in a variety of *emotional* states". With the scientific and technological progress, however, it has become possible to measure a broad range of physiological reactions to emotional challenges even in a non-laboratory setting. Several techniques have been used in the literature to study emotional processes and their influence on central system response (cortical oscillations) and physiological reactivity (autonomic responses), which are all relevant to the description of emotional field [58], [59]. In the context of the WA project, the human perception of stress is particularly important. The basis of the physiological stress model has its roots in the work by Cannon and Selye [60]. Cannon developed the "fight-flight" concept, which linked emotional expressions such as fear to physiological changes in the periphery. He emphasized the activation of the *Sympathetic Adrenal Medullary* (SAM) system in such situations, irrespective of whether the emergency reaction was "fight" or "flight". The markers of the fight-flight response are the catecholamines, epinephrine and norepinephrine, which increases when stress appears, and other physiological indicators associated with the autonomic nervous system. Thus, the SAM system is activated when the individual is challenged in its control of the environment, or is threatened, and this defence reaction prepares the body for battle or escape [61]. Epinephrine is also related to mental effort and cognitive performance. Increased epinephrine under normal levels of stress is associated with improved performance [61]. In fact, several studies show that stress, but only up to a certain level, improve performance, e.g. on selective attention tasks [62]. In fact, the cognitive psychology literature demonstrates that activation has an ''inverted U-shape'' relationship with performance in that some levels of activation may help an individual to perform at a level that is higher than their baseline state [63]. LeBlanc et al. [64] noted that general surgery residents had improved technical performance on task trainers when subjected to moderate stress conditions. On the other hand, excessive activation may lead to severe stress that overwhelms an individual or team, with resulting impairment in memory, attention, decision making, and general performance, regardless of previous training [65]. Therefore, stress is a physiological response to the mental, emotional, or physical challenges that we encounter. Immediate threats provoke the body's "fight or flight" response, or acute stress response. The body secretes hormones, such as adrenaline, into the bloodstream to intensify concentration. There are also many physical changes, such as increased heart rate and quickened reflexes. Under healthy conditions, the body returns to its normal state after dealing with acute stressors. Continuous monitoring of an individual's emotional and stress levels is essential for understanding and managing personal stress. A number of physiological markers are widely used for stress assessment, including: hormonal secretion, galvanic skin response, blood pressure, several features of heart beat patterns, and skin temperature.[58], [59]. The classical biochemical markers for stress are cortisol and epinephrine, which will increase rapidly to stress exposure. Also, activation associated with positive mood and pleasant activities will increase the levels of these measures. It has been proposed by some experts [66], that cortisol is a better marker if the emotional value is of interest. According to their theory, increased cortisol levels should be associated with inability to cope, lack of control of the stress situations, and depressive mood [67].

The empirical evidence for this hypothesis is so far limited. In particular, *Electrodermal Activity* (EDA) measured by *Galvanic Skin Response* (GSR) is a well-accepted indicator of reticular activation and, therefore, of emotion and cognition. A transient increase in skin conductance is proportional to sweat secretion. When an individual is under mental stress, sweat gland activity is activated and increases skin conductance. Since the sweat glands are also controlled by the sympathetic nervous system (SNS), skin conductance acts as an indicator for sympathetic activation due to the stress reaction [68].

An interesting stress measure is the fluctuation of *Heart Rate* (HR) over time. *Heart Rate Variability* (HRV) measures frequency fluctuations across time and reflects the autonomic balance, i.e. whether it is the *Sympathetic Nervous System* (SNS) or the *Parasympathetic Nervous System* (PNS) that is dominating. Stress usually causes a decrease in HRV. A decrease in HRV, in particular the 0.1 (Hz) component, is associated with increased mental effort [69] and some researchers interpret this measure as an objective indicator of mental fatigue. HRV can be measured as the standard deviation of the mean heart rate across time. However, a more sophisticated analysis is to analyse variability using power spectral analysis. Spectral analysis in the frequency domain enables a separation between vagal (PNS related) and sympathetic cardiac control to be made. The high frequency component (HF, 0.15-0.4 Hz) is mainly related to respiratory influences and solely controlled by PNS. There is also a low frequency component (LF, 0.04-0.15 Hz) and a very low frequency component (VLF, ≤0.04 Hz), which are controlled by both SNS and PNS. Some studies have also analysed the LF/HF ratio and observed that an increase is associated with mental stress (Sloan et al., 1994). It is important to control for physical activity, posture, breathing and speech, which will affect the variability components [3].
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Concerning the GSR signal, there are two components to be considered. *Skin Conductance Level* (SCL – phasic component) is a slowly changing part of the GSR signal, and it can be computed as the mean value of skin conductance over a window of data. A fast changing part of the GSR signal is called *Skin Conductance Response* (SCR – tonic component), which occurs in relation to a single stimulus. Boucsein provided an extensive coverage of early research of GSR related to stress [73]. He showed that slowly changing SCL and SCR aroused by specific stimulus are sensitive and valid indicators for the course of a stress reaction. Setz et al. [74] demonstrated the discriminative power of GSR in distinguishing stress caused by a cognitive load and psychosocial stress by using a wearable GSR device in an office environment. In addition, the SCL peak height and the SCR peak rate carry information about the stress level of a person [75]. Finally, under acute stress, sympathetically-mediated vasoconstriction causes a rapid drop in *Skin Temperature* (ST), and this influx of peripheral blood, along with stress-induced thermogenesis, simultaneously increases core temperature [76]–[78]. As with established hormonal stress markers, the core temperature increase, termed 'stress-induced hyperthermia' (SIH), is proportional to stressor intensity [79]. However, the act of inserting or implanting a probe to measure core temperature is invasive and, if applied within the period of measurement, it will be itself a stressor [80]. Skin temperature, in contrast, can be measured non-invasively using, for example infrared thermography (IRT), smart bracelet or chest bands [81]. In the context of the WA project, example of feasible sensors for the ECG, GSR, and ST signals recording are reported in Figure 3. Most of the current smart bracelets allow also collecting simultaneously and non-invasively several signals. However, movement and muscular artefacts could particularly affect the ECG signal quality while dealing with working activities. Therefore, a possible solution for HR and HRV estimation could be the use of video camera as demonstrated in many studies[82], [83]. Whereas, for the EDA and ST signals, smart bracelets or bands can be a robust solution.

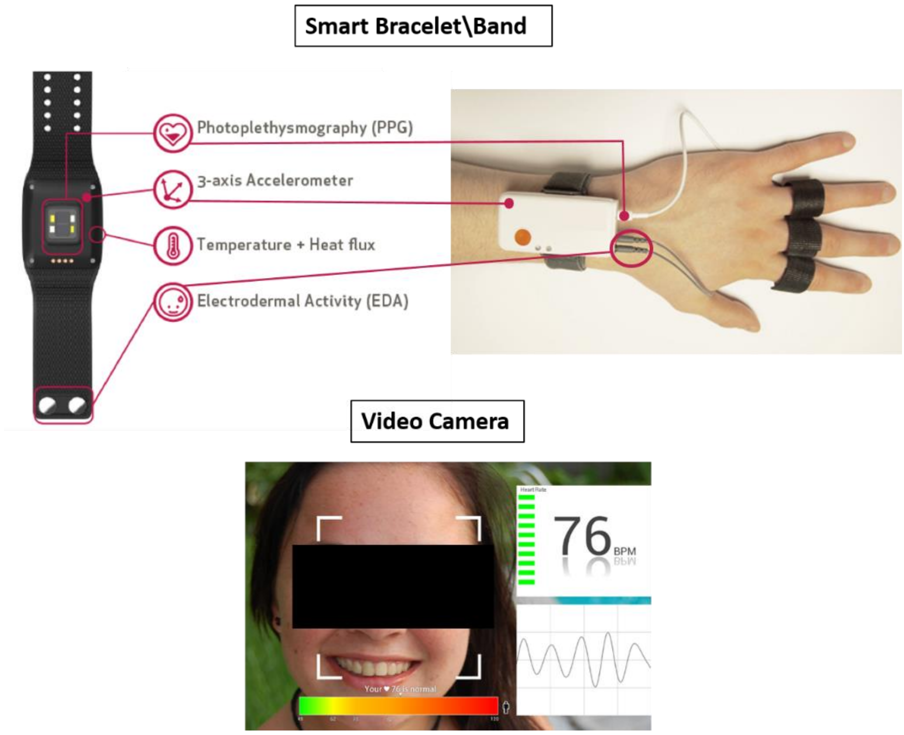

Figure 3. Example of wearable sensors for the estimation of the users' emotional and stress states while dealing with realistic tasks.

2.1.3 Eye Tracking (ET)

Various ocular measures have been investigated to measure mental workload in literature. One of the first was pupillary changes during mental activity, another index which has received consideration is the number of eye blinks during mental effort. Finally, the eye movements are associated with cognitive workload [84].

2.1.3.1 Measurement Parameters

2.1.3.1.1 Pupil diameter

Changes in pupil dilation result from contractions and relaxations of two eye located muscle groups, innervated by the autonomous nervous system. Thus, if the parasympathetic system is active, pupil diameter decreases, whereas action of the sympathetic system leads to increasing pupil diameter. This reaction of the eye is a protective eye reflex at first, regulating the incidence of light; but also provides information about increasing mental strain, which leads to wider pupils. Thus, pupil diameter can be used as an indicator for informational mental strain.

2.1.3.1.2 Blinking rate and duration

Blinking can be divided in spontaneous, reflective and arbitrary eyelid movements. Spontaneous blinking basically moistens the eye with tear fluid to clean and disinfect the cornea. In addition to that, it supports clear view after a long saccade. Reflective blinking protects the eye against any kind of external irritation, such as illumination stimuli. Empirical investigations have come to the conclusion that blinking rate can be used as an indicator for mental strain. Hence, results are controversial about the direction of pupil size. Moreover, there are studies that reveal a decreasing blinking rate connected to perception of visual information. In contrast, increasing blinking rate is an indicator for advanced training, little interest, increasing fatigue or non-relevant information.

2.1.3.1.3 Index of Cognitive Activity (ICA)

The index of cognitive activity provides physiological measurement of cognitive load based on changes in pupil dilation. An advantage of the ICA in relation to pupil dilation is the independency on light influences. The ICA separates light reflex from dilation reflex by means of a wavelet analysis according to the following function (1). For a given signal and a mother wavelet ψ, the process of wavelet analysis is expressed by:

$$\psi_{jk}(\chi) = 2^{\frac{j}{2}}\psi(2^{j}\mathrm{x} - \mathrm{k}) \tag{1}$$

where j is an index of dilation and k is an index of translation. The ICA only includes the dilation reflex wavelet of the pupil diameter. Moreover, the scaled ICA can be normalized through a hyperbolic tangent transformation to values of the interval [0, 1].

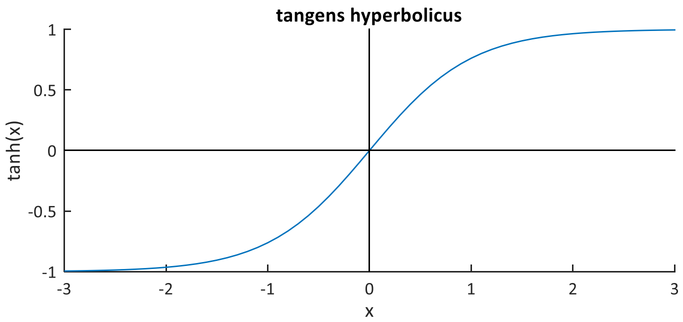

Figure 4. Tangens hyperbolics function

Hence, the ICA only contains information about the dilation reflex wave, which can be connected to cognitive load during a task. Due to light insensitivity of the measurement device, this method suits well for field investigation with lower standard conditions. The ICA will be measured by means of the FOVIO Eye-Tracking device, which is a remote eye tracker that will be placed directly at the HMI. The ICA will be tracked without calibration independent from light influences, as soon as the user is in front of the HMI. Thereby the mental strain while interacting with the machine will be measured without any need for action by the user. Even leaving and returning to the setting is possible. Thus, this system is very robust and suitable for field investigations.

2.1.3.1.4 Gaze analysis

Eye-trackers can detect the user's gaze point and gaze path by calculating the position of the pupil using video data from the eye based on a manual calibration. Eye tracking data will be used to detect mental strain, for instance based on repetitive eye movements. Furthermore, the part of the user interface that the user is looking at can be identified in real time. This allows classifying errors and interpreting holdup times to provide appropriate training lessons.

2.1.3.2 Methods

Either the eye position in space can be measured (point-of-regard) or the eye movement relative to the head can be measured. Three different main methods can be distinguished with regard to this classification:

- Electrooculography (EOG).
- Contact lenses methods.
- Videooculography (VOG).

2.1.3.2.1 Electrooculography (EOG)

Electrooculography measures the electrical voltage between the retina and the cornea which changes systematically with blinks, using electrodes. Various methods of electrooculography are possible (monocular, binocular, horizontal and vertical). Vertical EOG can be used to measure the blink of the eye because the movement of the eyelids during blink usually does not cause a significant signal in the horizontal EOG. In vertical EOG, the electrodes are placed above and below the eye [85]. A disadvantage is that the vertical EOG registers vertical eye movements as well as blinking eyes, both movements overlap in the signal, resulting in difficulties in determining the eye blink. An advantage when recording blinking rate with vertical EOG is the accuracy of the recording of a blink signal and most likely the high sampling rate. All blink parameters could be derived (amplitude, duration, speed).

2.1.3.2.2 Contact Lenses Methods

In this method, precisely fitted contact lenses are placed on the cornea of the user. Here again a distinction can be made between two procedures. Either a small coil or a small mirror is embedded in the contact lens. Using the coil, the exact positioning of the lens can be determined by inducing electromagnetic fields. This method has a high accuracy, but is only suitable for short periods due to the risk of oedema. Using the mirror, the reflection of a light through the small mirrors in the contact lens is recorded by camera.

2.1.3.2.3 Videooculography (VOG)

VOG determines the movement of the eye via video recording by measuring characteristics of the eye. Some examples are measuring the shape of the pupil, measuring the position of the limbus (transition between cornea and sclera) or measuring corneal reflection.

Cornea Reflex	By irradiating the pupil with light in the infrared range, the pupil margin can be determined and recorded.
Pupil Tracking	The eye is illuminated by an artificial, invisible infrared (IR) light source. Since the pupil absorbs the IR rays and thus reflects them less than the rest of the eye, the reflected IR rays can be recorded by an IR-sensitive camera.
Purkinje-Image Tracking	This method uses the different reflections of the light, e.g. infrared light emitting diodes, on the different optical boundary surfaces of the eye.
Limbus Tracking	The optical registration of the transition between the iris and the conjunctiva (sclera) is recorded; the high difference in brightness between the sclera and the iris provides a good distinguishing feature.

2.1.3.3 Eye-Tracking-Systems

Depending on which task is examined, different systems can be used. Two main characteristics can be distinguished: stationary systems and head-mounted systems.

2.1.3.3.1 Stationary Systems/Screen Based Systems

Stationary systems usually consist of two infrared light sources, a high-resolution camera in the infrared range and a monitor. The infrared light sources are used to generate a reflection at the cornea, which is recorded by the camera. The eye movement is then determined using image recognition methods. In Figure 5, an example of screen-based eye-tracker system (Tobii [86]) has been reported.

Figure 5. Example for screen based eye tracker (Tobii Pro X2)

2.1.3.3.2 Head-Mounted Systems

In head-mounted systems, a distinction is made between monocular and binocular systems. In monocular systems a camera and a mirror are attached to a headgear that records eye movement. The binocular systems use a separate camera and mirror for each eye.

Figure 6. Example for head mounted eye-tracking system (Tobii Pro Glasses 2) [86].

2.1.3.4 Addendum

Within and after this deliverable was produced, the technological decision as to which eye tracker should be bought and tested was made. On the basis of the defined criteria for the technology selection (Table 6) the final decision came down to the eye tracker model Pupil Core produced by Pupil Labs, which fulfills the requirements needed to perform the WA experiments as it is able to track pupil diameter, gaze and blinks and in addition meets the financial demands. At the time this deliverable was written, it was not clear which eye-tracking model would be used within the WorkingAge project, which is why only exemplary models were listed here.

In lab testing, however, will not only be using the Pupil Core eye tracker but also the Fovio FX3, this is due to the fact that the Pupil Core Eye Tracker is a less approved eye tracker model. The comparison of the two trackers will ensure that the Pupil Core eye tracker delivers reliable data for future use within the project. Further information is listed in D2.4, which describes, among other things, the advantages and disadvantages of the Pupil Core Eye Tracking System.

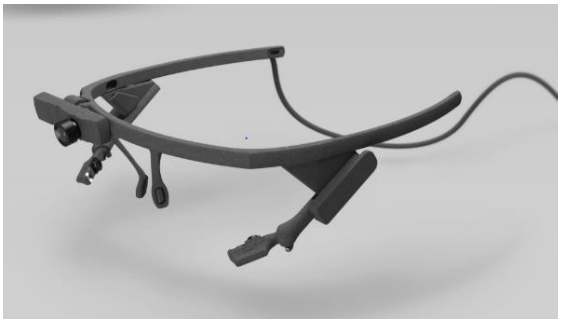

Figure 7. Pupil Labs Core Eye Tracking Glasses (https://pupil-labs.com/products/core/)

2.1.4 Sensors for physical workload: Electromyography (EMG)

A wide range of assessment methods has been developed to quantify workload as a function of external factors or to assess workers' response to workload. Objective methods are able to capture highly accurate data on a wide range of exposure variables such as joint motion or posture angles as well as response variables such as muscle activity or muscle fatigue. Electromyography represents such a procedure. Electromyography (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fibre membranes.

2.1.4.1 Method

There are two different methods of electromyography depending on the type of the electrodes:

1. Surface electrodes

   Due to their non-invasive character, in most cases surface electrodes are used in kinesiological studies. Besides the advantage of easy handling, their greatest limitation is that only surface muscles can be measured. For surface electrodes, Ag/AgCl electrodes are the most commonly used electrodes and are recommended for general use according to the European Recommendations for Surface Electromyography. (SENIAM).

2. Fine-wire and Needle electrodes

   For deeper muscles (covered by superficial muscles or bones), fine wire or needle electrodes are unavoidable. The sterilized paired or single hook wires are inserted with hollow needles and can be tested for correct localization with electrical stimulators or ultrasound images.

The following figure illustrates the possible measurable muscles (Figure 8).

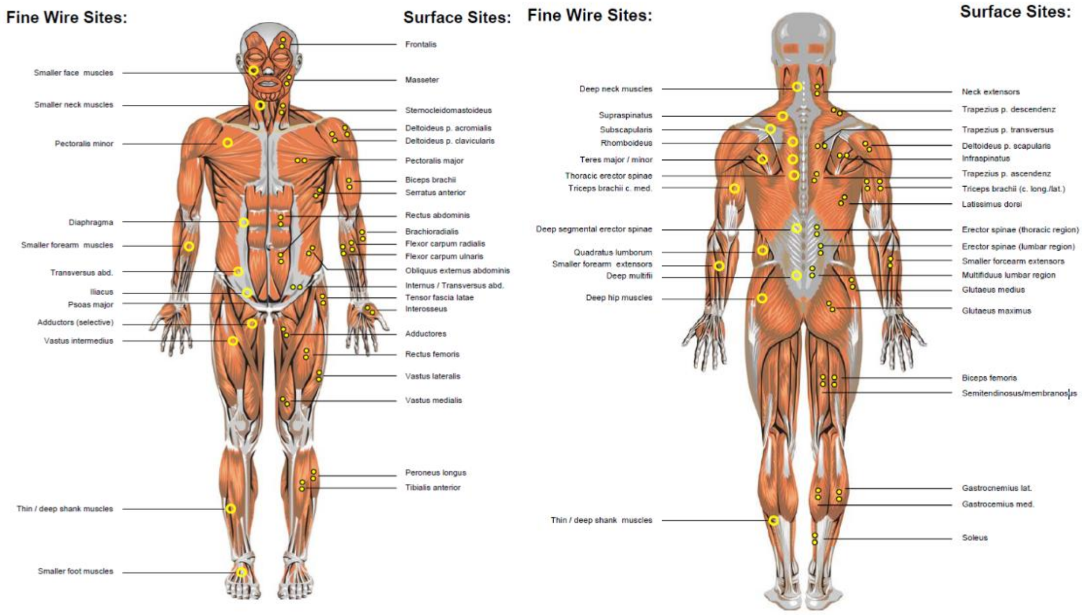

Figure 8. Anatomical positions of selected electrode sites, dorsal view. The left side indicates deep muscles and positions for fine wire electrodes, while the right side is for surface muscles and electrodes.

2.1.4.2 Signal Processing

The raw EMG recording already contains very important information and can serve as the first objective information and documentation of muscle innervation, but when a quantitative amplitude analysis is necessary, in most cases some EMG-specific signal processing steps are applied to increase the reliability and validity of the results.

Some of the most common methods are explained below:

1. **Full wave rectification:** All negative amplitudes are converted to positive amplitudes (the negative spikes are "moved up" to positive). Besides easier reading, the main effect is that standard amplitude parameters like mean, peak/max value and area can be applied to the curve (raw EMG has a mean value of zero).
2. **Smoothing:** Because the actual set of recruited motor units is constantly changing within the diameter of the available motor units and the arbitrary superposition of the action potentials of the motor unit. As a result, a raw EMG burst cannot be reproduced a second time due to its precise shape. To solve this problem, the non-reproducible part of the signal is minimized by applying digital smoothing algorithms that represent the mean trend of signal development. The steep amplitude peaks are cut away; the signal receives a "linear envelope". "Moving Average" (Movag) and "Root Mean Square" (RMS) are two established algorithms.
3. **Amplitude Normalization:** A major disadvantage of any EMG analysis is that the amplitude data (microvolt scaled) are strongly influenced by the given detection condition, they can vary greatly between electrode position, subjects and even daily measurements of the same muscle site.

One solution to overcome this "uncertain" character of scaled microvolt parameters is to normalize to a reference value. There are certain possibilities of normalization.

- **Internal mean or peak value**: The mean value or the peak value of the measurement can be used as the reference point. Both methods have the big disadvantage that all (at least qualitative) information about the degree of innervation is eliminated, e.g. an activation curve near the maximum capacity has the same dimension as a low level contraction. Any comparison between studies of the same subject and channel leads to the loss of the innervation ratio, which is a very important analysis factor for EMG findings.
- **MVC Normalization**: The most popular method is called MVC-normalization, referring to a **M**aximum **V**oluntary **C**ontraction done prior to the test trials. For each muscle to be tested, the maximum of contraction is measured first. Various exercises are necessary for this, typically, MVC contractions are performed against static resistance.

4. **ECG Artefacts:** The ECG can be considered as the EMG of the heart, but since the electrical synchronization is stronger by a factor of 1000, it can easily wander through body tissue and reach electrode sites on the upper body. Risk areas are the muscular sites close to the heart, such as the shoulder and upper arm muscles. By combining adaptive filter methods with a pattern recognition mode, sophisticated algorithms can "clean" most of the ECG content without affecting the actual EMG amplitude and power spectrum.

2.1.5 Vibration Sensors

Vibration sensors are moved from the WA Tool to questionnaires. This dimension is less relevant within the tool because it cannot be changed by the worker (compare to e.g. body pose ergonomics). The dimension will be evaluated through a questionnaire concerning long-term (external) factors.

2.1.6 Section Conclusion

As a conclusion, in the context of the WA experiments, EEG electrode solutions based on multiple-pins or soft materials (such as the solid-gel) and electrodes placed over an eye will be employed in the *In-Lab* experiments, and then eventually adjusted depending on the users' feedback and experimental results, for example by substituting the electrodes over the eyes with cameras, in order to reduce the device's invasiveness. With respect to all biomarkers, information available from ECG, GSR, and ST signals shows the highest correlation related to emotional and stress level (Sun et al., 2012). At the same time, nowadays, the acquisition of these signals is very simple, robust and non-invasive, thanks to the great variety of wearable devices already on the market, such as smart bracelets or bands, and video camera for HR estimation depending on the pixel intensity variations on the user's face. Concerning the ocular parameter, it will be selected based on the WA experimental studies, since the use cases variance is high, and different parameters might be suitable for different scenarios. Within the In-Lab studies, an eye-tracking device will be used, and parameters eventually adjusted depending on the results.

2.2 Subjective Data

User assessment will include a wide variety of characteristics that describe his/her abilities in performance and multiple information processing dimensions (physical, sensorial) as well as the definition of the current work context. It will include information in the following aspects: generic properties or constitutional characteristics (e.g. demographic background, psychological and physical); dispositional characteristics (e.g. age, personality, health), qualification & competence skills (e.g., work experience, performance, social skills, language skills and intercultural competences), preferences/aversions, or adaptable characteristics (e.g. strain, fatigue, motivation). Work context will include information related with Social and Organizational context. This data will be obtained from questionnaires and interviews with the workers. Work assessment will be made with the calculation of Overall Labour Efficiency/Effectiveness (OLE) and Overall Equipment Efficiency (OEE).

2.2.1 Questionnaire

WorkingAge will consider questionnaires for both subjective and objective data collection depending on the “what” and the “how” a particular aspect is meant to be measured according to the expected WA tool functionality, the design of the WA intervention, the system functionality, and the test trials. The following table (Table 1) considers different kinds of metrics that can be applied to obtain information about the primary user in different dimensions:

Table 1. List of metrics to obtain information about the primary user in different dimensions location system requirements by Use Case.

TARGET		DIMENSION	EXAMPLES OF QUESTIONNAIRES	DESCRIPTION
WorkingAge measures based on questionnaires on biopsychosocial functioning of the person	General health status	Medical History, current care plan and self-reported health perception	Checklist and gold questions (risk factors, diseases, current medical treatments, sensorial problems, aids, sleeping quality, physical state – IMC, stress/ anxiety symptoms, etc.)	Anamnesis/ semi-structured interview
	Psychological functioning assessment	Cognitive (status and performance)	Montreal Cognitive Assessment (MOCA)	Screening test designed to detect early or minor cognitive impairment. It was validated in the setting of mild cognitive impairment, and has subsequently been adopted in numerous clinic settings.
			Prospective-Retrospective Memory Questionnaire	In order to understand why people make memory mistakes, we need to find out about the kinds of mistakes people make, and how often they are made in normal everyday life.

			WA system detection and/or proposed intervention	
		Emotional / Affective	Geriatric Depression Scale (GDS)	Instrument to assess depressive symptoms and screen for depression among older people.
		Other: reporting stress / anxiety levels	Depression, anxiety stress scale (DASS-21)	Measure the three related negative emotional states of depression, anxiety and tension/stress
			Hamilton Anxiety Rating Scale (HAM-A)	Scale developed to measure the severity of anxiety symptoms, and is still widely used today in both clinical and research settings.
	Physical	Physical status	Rapid Assessment of Physical Activity (RAPA)	A 9-item, self-administered questionnaire used to assess and monitor physical activity levels of adults aged 50 years and older. The RAPA evaluates the level and intensity of leisure time physical activity, from sedentary to vigorous activity, as well as strength and flexibility training.
		Physical Activity	PASE - Physical Activity Scale for the Elderly or Rating of perceived exertion (RPE) – Borg scale	Widely used and reliable indicator to monitor and guide exercise intensity allows individuals to subjectively rate their level of exertion during exercise or exercise testing
		Frailty	Tilburg Frailty Indicator (TFI) [Part B]	A user-friendly questionnaire for screening frail community dwelling older people, including only self-reported information. Part B contains 3 domains of frailty with a total of 15 questions on components of frailty, so it assesses the presence of frailty in concrete terms. Participants are asked to rate their exertion on the scale during the activity, combining all sensations and feelings of physical stress and fatigue.
		Physical Performance	WA system detection	
	Social environment	Social connectedness	Lubben Social Network Scale-Revised (LSNS_R)	A self-report measure of social engagement including family and friends. Tool designed to measure perceived social support received by family, friends and mutual supports.
	Behavioural situation	Nutritional Habits	General nutrition knowledge questionnaire (GNKQ)	Can be refined and implemented as a quiz (used to inform about recommended nutritional habits)
			Adult Eating Behaviour Questionnaire (AEBQ)	Measure 8 appetitive traits, including 8 scales encompassing both food approach and avoidance appetitive traits.

			Self-Regulation of Eating Behaviour Questionnaire (SREBQ)	Applied to assess participants healthy eating intentions.
			"How healthy is your diet questionnaire"	Assess the nutritional value of the participant's diet. Answer the questions and then read the supplementary information will help the participants to consider making changes to their diet. Questions can be made in form of quiz and the supplementary information can be useful for the nutritional recommendations system.
		Sleeping Habits	Pittsburgh Sleep Quality Index (PSQ)	Learn about participant normal sleeping habits. It differentiates "poor" from "good" sleep quality by measuring seven areas/components over the last month.
		Daily Living Routines & Daily Functioning	Create an adapted version of Individually prioritised problem assessment (IPPA Form)	Implemented through an interview and questionnaire. Before any equipment or assistive technology is selected, up to seven problems in daily activities that need to be addressed may be identified. The assessment provides a baseline taxonomy to help the reference to difficulties, and it can be extended with the areas or activities that WA is oriented to support. The part II of the follow-up assessment is implemented few months after starting the use of WA system. In this way, the frame of reference for the baseline situation is maintained and the effects are assessed in that context. The difference between the total IPPA score before and after provision of new assistive technology is considered to represent the effectiveness, thus indicating the degree to which the perceived inconvenience with respect to the problems has diminished.
		Risks behaviours	Checklist of daily life risk behaviours	
	General wellbeing & Quality of Life	**General wellbeing & QoL**	Satisfaction With Life Scale (SWLS)	A multi-item scale that measures satisfaction with life as a cognitive-judgmental process.
			EQ-5D	A preference based measure of health status that has been used widely in several European countries for the measurement of health-related quality of life or health outcome. The instrument comprises 5 dimensions (mobility, self-care, usual activities, pain/discomfort, anxiety/depression).

			WHOQOL-BREF or other related questionnaire such as Health-related quality of life	A 26 items abbreviated version of the WHOQOL-100, a quality of life assessment that cross-culturally applicable.
	Occupational aspects https://www.ccohs.ca/oshanswers/psychosocial/fit_to_work.html This is a very interesting app offering fact sheets from hazards to diseases, to ergonomics, to workplace promotion… It can be reviewed so to pick up important questions for assessment and recommendations (OSH Answers) Other guidelines: ▪ Work Health Assessments Online assessments based on service fees: https://www.healthshield.co.uk/our-products/online-occupational-health-questionnaires/	**Daily Work Requirements & performance**	Survey to be developed in WP2 and WP3. It can include profile description, a checklist of physical demands, etc. We can use as reference the "Occupational Requirements Survey" (ORS). The survey includes questions to collect information about the following: problem solving; work review; the pace of work; interactions with others.	NOTE: difficult to get access to the questionnaires and surveys, once it is a widely exploited scope. Copyrighted and access under payment terms. Maybe it will be necessary to have partners support on review and in defining an adapted survey per each "working profile".
		Working conditions and Work related health risks	Self-report and/or Checklist on risks assessment	
			Ergonomics in the work environment/ daily work routines	Description provided by semi-structured interview and/or checklist Ergonomics is one of the dimensions normally assess within risks assessment
			Questionnaire on Subjective identification of occupational health problems Example of questionnaire	
		Attitudes, satisfaction and motivation	Questionnaire on work-related wellbeing	Questions on subjective work-related wellbeing; quality of work; interpersonal relations…
			Employee Attitude Survey This link orient to the steps for developing and implementing an Employee Attitude Survey https://hr-survey.com/EmployeeAttitude.htm	The results of this type of feedback process provide an understanding of how the employee perceives the organization along different dimensions.

			Evaluation of employee satisfaction See example of questionnaire page 82 to page 85 Other source for inspiration "Motivational employee satisfaction questionnaire"	Questions in a Likert scale to assess satisfaction with job; Satisfaction with the combination of family and work;
		Physical Functional Abilities relevant to work requirements	Self-report questionnaire	To provide individual's perspective on his/her change in function, which may help shed light on the person's (perceived) ability to perform work beyond that which range-of-motion assessment might provide. E.g. ability to lift a specific amount of weight, visual acuity, hearing capacity, etc. It can be implemented join with physical performance measures/tests that will complement information to determining his/her ability to sustain work on a regular and ongoing basis.
			Human Activity Profile (HAP)	Used to evaluate physical activity in a wide variety of clinical populations and in healthy individuals, a self-report measure of energy expenditure or physical fitness.
		Functional Abilities (physical function and behavioural health) relevant to work requirements	Functional and/or work capacity evaluation (FCE/WCE). There are different FCE instruments that need to be analysed for selection. // or the Work Disability Functional Assessment Battery (WD-FAB)	We couldn't find the original battery. Mention 15 minutes estimated time for its implementation.
		Organizational structure and culture	Questionnaire on Occupational Health policies and measures implemented in the organization	Shortened version of the ELSI Questionnaire

2.2.2 Interview

Interviews are conceivable at different times in the WorkingAge project. Focus groups, personal interviews and expert knowledge could be used to define the functional requirements of the HCI solution in a customized way. In this way, user-relevant views and requirements can be recorded and differentiated. The fulfilment of user needs and the success of the usability of the system will be proprietary. Focus will be given on the specification of the desired features for the WA Tool, desired assistance and recommendations. The interview may also provide information on technical limitations and conditions under which the system must operate. A further place of the use for interviews in the WorkingAge project are the test sessions (in lab and company). Interviews and questionnaires are used to collect feedback on the accessibility, usability, effectiveness and health of the WA Tool. Further, the validity, sustainability, usability and applicability of the WA Tool will be surveyed, as well as proof of the basic social, psychological and biological characteristics, commitment, compliance and effectiveness, and proof of user-friendliness and health effects (physical, psychological and social well-being). Interviews can occur in a variety of forms, in particular, some essential distinguishing features are listed below [87]:

1. Extent of structuring.
2. According to the type of contact (direct, by telephone, in writing).
3. According to the number of persons interviewed (individual interview, group interview).
4. According to the numbers of interviewers.
5. According to the function of the interview.

The extend of structuring is one of the most important points influencing the interview. Three different structuring strengths can be distinguished [87]:

- **Structured Interview:** The wording and sequence of the questions are clearly defined and binding on the interviewer. It requires precisely formulated questions that can be answered as briefly as possible by the interviewer. This type of interview is suitable for those topics with extensive previous knowledge, as it is the only way to formulate the questions appropriately and select exhaustive alternative answers.

- **Unstructured Interview:** Only the subject area is given, the conversation is open. The personality of the interviewer is of crucial importance. Not only the way he conducts the conversation but also his individual thematic preferences affects the result. A typical technique is the narrative interview. It starts with a narrative impulse by the interviewer, then the interviewees speak freely and unrestrictedly. In this phase, the interviewers do not express any doubts and do not ask for reasons, but simply keep the conversation going. Subsequently, the interviewer may ask questions of understanding. In such a qualitative design, the views of the respondents are captured in depth and understood as embedded in their social context. The evaluation is often very extensive.

- **Semi-Structured Interview:** Contains partly open, partly closed questions. Characteristic for this type of interview is a guideline, which more or less prescribes the type and content of the interview to the interviewer.

The final nature of the interview must be determined according to the research question and the aim of the interview.

2.2.3 Section Conclusion

The type of interview should be chosen on the basis of the research question and according to the respective use case. The interview to define the requirements of the HCI solution is intended to identify unknown requirements that are considered relevant by the users. In this case, focus groups can be used as a form of interview. Focus groups are a special form of group interviews, which are usually based on a guideline, i.e. a semi-structured interview. Their use is particularly useful when ideas are to be developed, concepts created and requirements asked [88]. For the second part, the In-Company tests, the dimensions to be inquired are already determined. A questionnaire is particularly useful here, but a structured or semi-structured interview is also possible for extension purposes.

2.3 Behavioural Data

Strongly linked with Lifestyle Indicators, the conduction of a healthy lifestyle often leads to the improvement of the emotional conditions of the user. The user-wellbeing is as important as his/her physical conditions, being both part of the health status of the user. As such, the WA project will make use of behavioural analysis based on the user motion, physical activity routine and voice analysis to infer the user mental and emotional state.

2.3.1 Body Pose

Body pose provides a useful information in areas such as augmented reality, video games, entertainment, surveillance and security [89]. The body pose can be measured in two different ways [90][91][92][93][94]. Firstly, wearable devices could be employed by users in order to continuously estimate their body pose. However, these kinds of devices are intrusive and users may refuse to wear them. One of the most common methods is based on employing markers (passive or active) near each joint to identify their motion and pose. Another option is to use sensored T-shirt recording. However, for the WA pilots this implies, apart from being an intrusive sensor, additional unpractical handling like the need for washing T-shirts (a second T-shirt would be needed) etc. and is therefore not considered in this scope. An alternative to this is the use of cameras to estimate the body pose. Computer vision is a non-intrusive alternative to wearable devices. On the other hand, the accuracy of computer vision is lower. The most common sensor system devices tend to be either 3d or 2d cameras. The 3d cameras (we can include in this category the time-of-flight devices) supply both RGB images and the depth information usually by means of the disparity map [95]. The disparity map represents the depth information as grey levels where pixels with high level (near to white) mean closer from the camera and lower levels (near to zero) mean further from the camera o devices. 2d cameras only supply RGB images, but present some advantages and disadvantages with respect to 3D cameras o devices. Although the price of the 2D camera is lower, its computational intensity is not as high as a 3D camera. On the other hand, the biggest drawback of the 2d cameras is its lower accuracy, especially in the estimation of depth measurements.

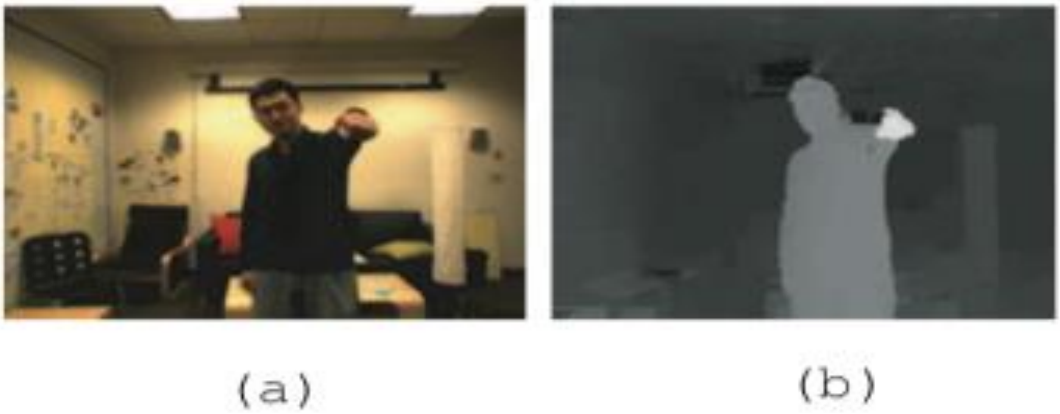

Figure 9. Example of RGB image (a) and disparity map (b) from [96].

Once the different sensors available for body pose estimation have been enumerated, it can be concluded that a 2D camera is the best likely option for use for the body pose sensor estimation in the WA Tool. The main reasons for this choice are the low price of the sensor, with has a significant impact on the cost of the global solution (one camera for each workstation), and the fact of it is a non-intrusive sensor, which decreases the probability of non-acceptance of the system by its users. Body posture estimation methods based on 2D images [97] supply the body pose of the user as the location of the main joints and body parts such as head, shoulders, knees, hips. Joint locations usually are expressed as image coordinates measured in pixels, which could make difficult to assess the ergonomics (see Figure 10).

Figure 10. Example of 2d joint detection from [98]

The recent developments in deep learning, more especially in Convolutional Neural Network (CNN) allow employing 2D images as input (see Figure 9 (left)) and obtaining as a result the location of the joints in world coordinates (3D coordinates) [99] (see Figure 11 right) . Being able to dispose of the location of the joints in 3D coordinates is essential to estimate the angles between joints in order to assess body postures by methods of ergonomics like OWAS, RULA or REBA [100]. A major drawback of the deep learning implementations is that they are high demanding of examples in the training and validation process of the neural network. These examples are composed of 2D images and the actual locations of the joints -3D coordinates- (ground truth) which normally are taken by hand. For this reason we will deploy a 3D sensor (camera or time-of-flight device) during the InLab tests.

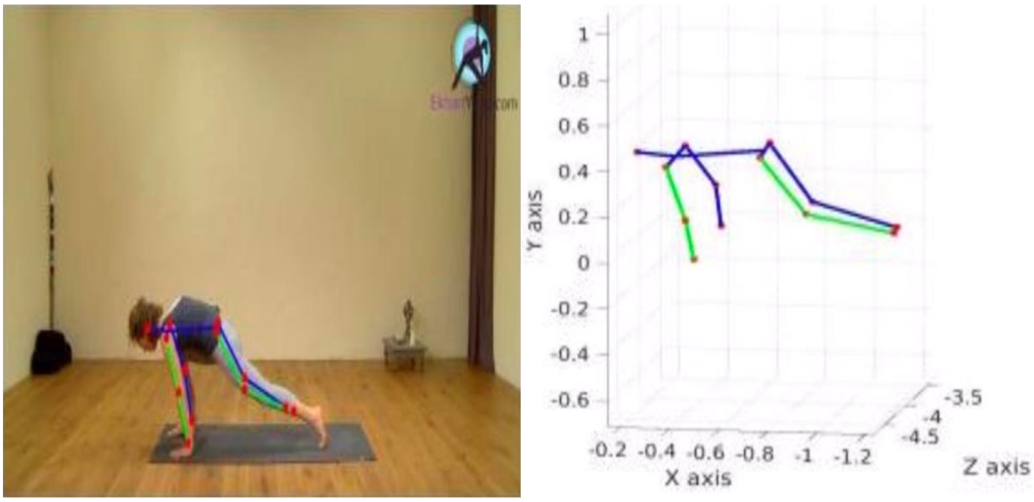

Figure 11. RGB image with joint 2d estimation (left). 3D joint estimation (right) from [99]

2.3.2 Voice Analysis

Voice is a decent indicator of the state of a speaker. By processing speech and voice, not only the machine can recognize the content of speech and extract its positivity or negativity, but also the way the speaker talks (e.g., angry, happy, stress). This has been done through real-time feature extraction and novel classification techniques. Various studies [101]–[104] concluded that stress causes variations in the voice features: increase in the fundamental frequency, decrease in the F1 and F2, difference between Chirp and Fourier transformations, vowel durations, decrease in the duration of the spoken words. Within the WA project, the extracted states from speech will be added to the emotional profile of the participants for further processing. Moreover, a Voice Activity Detection (VAD) process can be deployed to only process the segments in which the participant is talking. This is also useful to reduce the size of the recorded data. In terms of hardware, voice recording can be done separately through microphone attached to a PC, Mobile phone, or Raspberry Pie, or we can use a webcam for recording both facial expressions and speech. The most important is to have high quality recording. Some alternatives to choose from (see Figure 12):

- Rode SmartLav+ Lavalier omni-directional microphone, which has a good quality and a TRRS connector, and therefore can be connected to PC/Mobile Phone/Raspberry Pi. Cost is about 50 €. This is probably more suitable for the “drive” use case, because it is less harmful in case of accident, and in the “office” use case, as it is less intrusive. Signal-to-noise ratio needs to be investigated.

- Headset with noise-cancelling mic, as the Sennheiser SH330 IP. Connector could be USB or proprietary. Cost is about 90 €. Headsets usually incorporate mono/stereo speaker(s), and this is useful for providing vocal messages to the user. This solution is probably more suitable for the “manufacturing” use case, where the environment could be quite noisy.

Both microphones mentioned above should be connected to a radio transmitter (TX), while a receiver (RX) should be connected to, for example, a PC. This can be done in several ways (see Figure 13):

- Bluetooth TX-RX
- Ad-hoc (B band or 2.4 GHz) TX-RX
- Wireless microphones (again, supporting Bluetooth or ad-hoc)

Concerning noise reduction, software considered interesting to test is RNNoise (https://people.xiph.org/~jm/demo/rnnoise).

Figure 12. Example of mics. A Lavalier mic. on the left, a headset on the right.

Figure 13. Some wireless options: B band, 2.4GHz, Bluetooth.

2.3.3 Facial Expression

Understanding facial expression is very important as this can reveal emotional states and intentions of people. Facial affect analysis can be performed in terms of prediction of expressions, valence (positivity / negativity) and arousal (activity level) of the expression and the detection of activated facial action units (e.g., AU 1 – inner brow raiser; AU 2 – outer brow raiser; AU 12 – lip corner puller etc.). Examples are shown in Figure 141. Within the project, these analyses will be achieved in real-time by focussing on the design and evaluation of deep learning based frameworks for facial affect analysis. The facial affect will be estimated from images captured from two 2D cameras. One for the front view and one for the profile view. The cameras can be webcams attached to PC, mobile phone, or Raspberry Pie. The quality of captured image/video data is important. To achieve high quality data, the cameras should be fixed without large movements and the surrounding environment should have good lighting condition. For captured images, the minimum requirement of resolution for the entire image is 640x480 pixels, but we recommend 1280×720 pixels. The minimum resolution requirement for the facial area is 96x96 pixels, in order to train accurate models for expression and AU prediction. To enable spatio-temporal AU analysis, video sequences should be captured. The minimum frame rate requirement is 25-30fps. Only the segments of video where a face is present should be recorded for the purposes of this module.

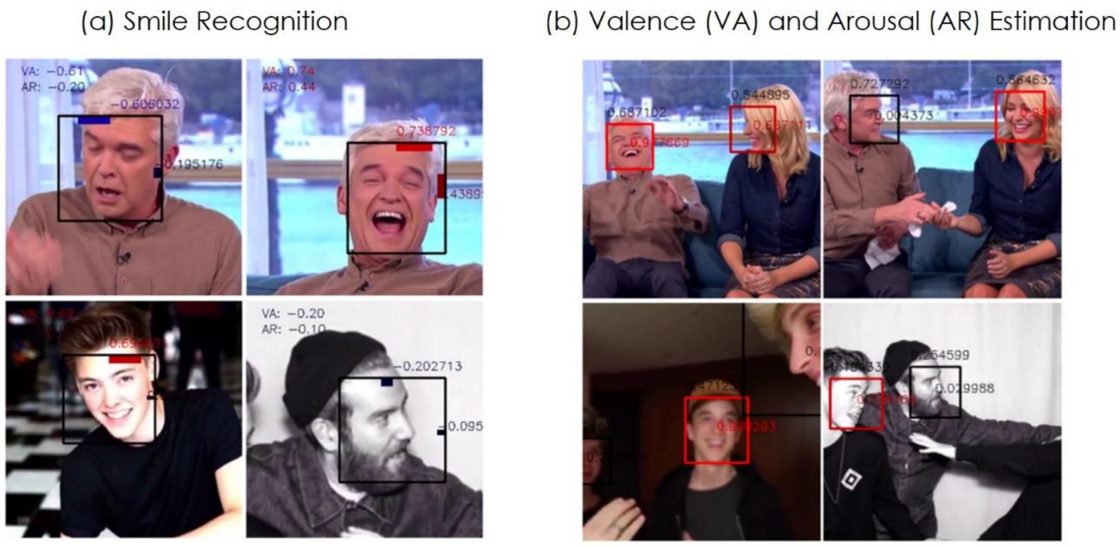

Figure 14. Examples of Facial Affect Analysis tasks.

2.3.4 Gesture Recognition

In the context of the WA Tool, and more precisely T4.2, the software and infrastructure enabling minimal gesture interaction with the system will be developed. Apart from this minimum requirement that is described in the DoA (page 21), and should the resources be adequate, there is the possibility of exploiting the same sub-system as a basic indicator of mental strain (e.g. by assessing the frequency or speed of gestures and comparing them against the average for the same user, signs of stress could be deducted). Hand gestures are considered as a promising area for researchers when it comes to designing a natural and intuitive method for HCI. Contact based devices employed for hand gesture recognition systems are based on the physical interaction of the user with the interfacing device. These devices are usually based on technologies like data glove, accelerometers and multi-touch screen, which, in turn, uses several detectors. Also, there are devices that use only one detector as the accelerometer of the Nintendo Wii-Remote. This class of contact-based devices for hand gesture recognition can be further classified as mechanical, haptics, ultrasonic, inertial and magnetic [105].

2.3.4.1 Infrastructure

For the interaction with the system, the intention is to use off-the-shelf devices utilising advanced image processing and machine vision algorithms to track the users hand gesture and then convert them into commands. Such devices are SoftKinetic, PointGrab's, HandGKET, Mgestyk, GestureTek, WiiNitendo, Microsoft Kinect, OMRON, eyesight's, HandVu and Eyetoy. PointGrab's enables the integration of hand gestures with application such as games and customized user interfaces that are based on unique sophisticated hand shape and motion detection algorithms working together with a standard 2D camera. HandGET has the toolkit that facilities integration of hand gesture control with games and VE applications. The middleware used in this product recognises user's hand gestures and generates keyboard and mouse events to control applications based on computer vision techniques. Mgestyk, developed in 2009, employs software for hand gesture processing and 3D camera to interact with computer for operating games and applications. Based on the technology of 3D camera for computer vision, camera in mobile device and pointing frame GestureTek product is used for applications like controlling pc, mobile or console applications using camera or phone. Wii Nintendo has wireless and motion sensitive remote with game console and may be used for game with any pc etc. Another product HandVu launched in 2003 is also used for interaction with computer to operate games and application based on real-time gesture recognition using computer vision techniques. OMRON Corporation developed a new hand gesture recognition technology capable of simultaneously recognizing the position, shape, and motion of a person's hand or finger by referencing a camera-recorded image. By combining this technology with OMRON's core facial image sensing technology, gesture recognition can be started automatically based on the analysis of interrelation between the position or direction of the face and the hand shape or position. A comparative table concerning the aforementioned technologies is presented in Figure 15.

Technology (Year)	SoftKinetic (2012)	PointGrab's (2012)	HandGKET (2011)	Mgestyk (2009)	GestureTek (2008)	Wii Nintendo (2006)	Microsoft Kinect (2012)	OMRON (2012)	eyeSight's (2012)	HandVu (2003)	Eyetoy (2003)
Platforms											
Windows	x	x	x	x	x	x	x	X	x	x	x
Linux	x	x						X			
Android		x						x			
Languages											
Java					x	X					
Python								x	X		
C++	x	x	x	x		x	x	x	x	x	x
C#											
Other		x			x		x			x	X
Input device											
Camera	x	x	x	x	x	x	x	x	x	x	x
Multitouch					x				X		x
Wii Remote						x					
Windows 7 touch	x	x				x	x		x		
TVIO	x	x			x						
Other			x					x	x	x	
Feature											
Standard gestures	x	x	x	x	x	x	x	x	x	x	
Custom gestures	x										

Figure 15. Existing technologies of gesture recognition.

2.3.4.2 Software

Based on the research conducted, the platform which supporting the gesture recognition infrastructure, is highly likely to be selected among OpenCV, MATLAB, A Forge.Net, and iGesture. OpenCV has BSD license which enables usage of the framework for both commercial and research purposes. Some example applications in OpenCV library are object identification, segmentation and recognition, face recognition, gesture recognition, motion tracking, mobile robotics etc. MATLAB supports hardware for Linux, MacOS X and Windows platforms providing extensive cross platform compatibility. MATLAB provides Image Processing Toolbox which entails a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization, and algorithm development. Different task like image enhancement, image deblurring, feature detection, noise reduction, image segmentation, geometric transformations, image registration, object tracking, recognition etc can be performed using the toolbox. The A Forge.NET framework is compatible with .NET Framework 2.0 and above. This framework can be easily integrated with Microsoft Visual Studio IDE for development. The framework consists of set of libraries and sample applications that can be used as a basis to develop a gesture recognition application. iGesture is a well reputed and older gesture recognition framework is iGesture. This framework is a Java based and focused on extendibility and cross-platform reusability. The distinctive feature of the iGesture framework is that it supports both developers and designers to develop new hand gesture recognition algorithms. iGesture integrated framework includes the gesture recognition framework and the 'I' gesture tool component to create custom gestures sets. This makes it better compared to other frameworks as the other frameworks have predefined gestures and the developers are limited to those gestures. Also, iGesture tools provide the ability to evaluate the usability, performance, effectiveness of new and existing hand gesture recognition algorithms. The main disadvantage of this framework is its long learning period because of the extensive usages the framework offers the developers must have a good understanding of the principals and methods of using this framework in software applications.

2.3.1 Section Conclusion

Conclusively, as many off-the shelf components as possible will be adopted to develop a technologically mature platform which will enable a gesture-based interaction with the WATool. The selected technology will probably consist either of one of the infrastructures mentioned in Figure 15 coupled with a compatible software or by a commercially available camera as an end device. The latter will probably allow the development of a facial recognition-based ID verification to ensure that the right person that is being monitored by the system and that any affected employees around them are automatically excluded. This is not included in the DoA, but if deployed, it can be of value for the rest of the WATool components as well.

2.4 Environmental Data

2.4.1 Illumination

Illumination is a key factor for the ergonomic design and analysis of workspaces. While proper lighting creates safe and comfortable environments, inadequate lighting may cause visual fatigue, visual conditions, decreased performance, and may even lead to serious and severe accidents. ISO 8995-1:2002 establishes the requirements for lighting of indoor work places so that workers can perform visual tasks efficiently, in a comfortable and safe environment through their working hours. According to this standard, good lighting requires equal attention to the quantity and quality of the lighting. Since visibility depends on the way in which the light is delivered, the colour characteristics of the light source and surfaces together with the level of glare from the system. The standard provides recommended Maintained Illuminance, Limiting unified glare rating, and Minimum colour rendering index values for rooms based on the activities that are performed in them. However, there are additional factors that can be taken into account when evaluating the lighting quality of a workplace, (not all of them already covered by the standard) namely:

- Task specific visual requirements.
- Age, since the people's perception of lighting varies with age.
- Uniformity of illumination through the area where the task is performed.
- Type of light source, since it affects light directionality, flickering, colour temperature, stroboscopic effect, etc.

Measuring illuminance taking into account parameters such as task, age, and uniformity (without excluding any other parameter that the project development may identify), will provide the WA Tool enough information to assess the lighting quality of a workplace. To do so, **a target illuminance measurement accuracy of ±10 % for a range of 100-3000 lux is established**. The proposed process to assess lighting quality consists of the following stages:

1. Derivation of the illumination needed for the task. A classification of tasks is included in the ISO standard.
2. Correction by age. Several methodologies enable the correction of the minimal illumination threshold, depending and the age of the user.
3. Compare the minimal illumination level obtained with the level measured at the workplace.
4. Uniformity. Compare the minimum value with the average value. The ratio between the minimum and the average values should not be lower than 80%

2.4.1.1 Light measurement technologies

Four main sensor technologies are used in the measurement of ambient light:

1. CdS - LDR (*CdS Light Dependent Resistors*) are Cadmium Sulphide based components featuring a variable resistance that changes as light strikes their surface. Their main advantages are their human eye resembling response and their high sensitivity and stability. Although they may seem the most suitable choice at first, their major disadvantage is that they are not RoHS compliant, and, therefore, cannot be used to manufacture electronic products to be sold in the EU.

2. Photodiodes. These semiconductor devices convert light into electrical current. They feature large repeatability through large production batches, but their output is a small signal current, which requires complex signal conditioning stages such as amplification, filtering, etc.

3. Phototransistors. Phototransistors also output electrical currents, altering the current flowing from their emitter to their collector as they sense different light levels. While they offer higher output currents than the photodiodes, their manufacturing repeatability is lower, and the temperature

dependence of its response is higher.

4. Integrated Circuits (ICs) / Application Specific Integrated Circuits (ASICs). Light sensing integrated circuits are usually based on photodiodes but surpass them by featuring embedded signal conditioning, digital outputs, human eye resembling response, reduced size, and more.

2.4.1.2 Available sensors and devices

There is a wide range of available light measurement sensors, devices, and solutions. As the result of the analysis of said range of available options, three different approaches that could provide WA with the necessary tools to perform light measurements have been identified and are presented below.

2.4.1.2.1 Light sensing mobile APPs

By making use of the embedded Smartphones sensors, several light sensing APPs are available for iOS and Android OS. At first glance, this approach stands out as the most simple, inexpensive and easy to deploy solution, but an assessment of performance and features also reveals some concerns about their suitability according with the WA Tool technical specifications and requirements.

Advantages:

- No additional hardware is required.
- Non-intrusive measurement, highly convenient for the user.
- Reduced cost if the APP is used “as is” and no additional developments are required.

Disadvantages:

- Measurements are highly model-dependent on most Smartphones.
- Measurements show significant deviation between different APPs.
- Studies and tests [106]–[108] show far higher accuracy deviations that the proposed target accuracy of ±10 %, and their conclusions do not endorse the use of these APPs and Smartphones as accurate light measurement devices.
- The APPs do not provide access to sensor raw data, which is a major drawback for the WA Tool purposes.
- Custom software could be developed to enhance the response of the Smartphone sensors but a development costs evaluation is due to compare the costs to the acquisition of a commercial device, or even the development of a custom designed one.

2.4.1.2.2 Custom designed device

Designing and developing a custom solution that can measure light and send the data through the most convenient communication interfaces could be the most flexible option for its integration within the WA Tool and architecture. However, the following aspects must be taken into account as they represent both advantages and disadvantages.

Advantages:

- A custom solution always means seamless integration with the system.
- The use of light sensing ICs would allow to develop reduced size and non-intrusive, battery operated devices.
- Every data collected by the device would be accessible, and custom data transfer protocols can be implemented.
- The device hardware would feature low costs, which would allow the manufacturing of a relatively large number of units.

Disadvantages:

- Calibration of the custom devices to perform as commercial calibrated devices would not be feasible. The cosine correction lenses and diffusors implemented in commercial devices would not be available for these kinds of devices, which means that their measurements would not be similar in certain situations. Partial calibrations or threshold comparison with commercial calibrated devices would be an option, but no linear response can be guaranteed. An assessment of the use of a non-calibrated device and the linearity of its response could be useful to evaluate the viability of the development of such a device.
- Measurement accuracy would be limited by the lack of calibrated and compensation elements that would not be possible to specifically design for the custom device.

2.4.1.2.3 Commercial lux meters

Acquiring off the shelf light measurement devices is the most reliable approach for precision measurements. Both calibrated and non-calibrated commercial devices are available in the market, the latter being less expensive. There is also a wide range of commercial lux meters featuring communication interfaces to access the measurement data, which makes them suitable for implementation within the WA Tool architecture.

Advantages:

- Fastest deployment and shorter development times.
- Most accurate, corrected, and reliable measurements, even more so when using calibrated devices.
- Most devices offer not only illuminance measurements, but also additional ones, and data logging.

Disadvantages:

- A certain degree of custom design and development might still be required to acquire, process, and send the measured data to the WA Tool. For example, Serial to Wi-Fi interfaces, proprietary protocol interfaces, etc.
- These devices are larger than smartphones or any custom solution, so workplace ergonomics may be affected.

- Automatic or remote operation of the device is not always available or featured, so the worker may have to activate the measurement manually.

2.4.2 Surrounding noise

While driving, working inside an office or a manufacturing part, environmental noise such as colleagues speaking, things breaking, cars horning, can affect emotional state of the worker and/or increase their stress. Through extracting features such as loudness, abrupt changes in acoustic signals, voice activities, we may find variables that correlate to the emotional state of the worker. To capture audio, we only need a high-quality microphone similar to as discussed in Voice Analysis section (however without any noise cancellation). As the Location functionalities of the WA Tool strongly depends on the Use Cases, the described technology and sensors will be adapted accordingly with the user's feedback.

2.4.3 Thermohygrometric and CO_2

Temperature (T), relative humidity (RH) and CO_2 levels influence the comfort of workers.

European Commission Directives exist for limits of these levels (e.g. 2006/15/EC for CO_2); however, applicable legislation is different for each EU member state. Moreover, in the case of exposure to CO_2, the directive is considering it as a pollutant concerning *health and safety* of workers. Given the WA contexts this is very unlikely to happen – instead WA should study *comfort* levels, for CO_2 and also for T and RH. By means of example, the European Directive states 5000ppm as a limit for continuous CO_2 exposure, while levels above approx. 1000ppm are considered as uncomfortable [https://en.wikipedia.org/wiki/Indoor_air_quality], causing drowsiness and headaches. Adequate ventilation reduces CO_2 levels.

WA will investigate if correlations exist between T, RH and CO_2 levels and strain. The age factor will be interesting in this; e.g. elder people could prefer a higher ambient temperature, this can be cause of friction when sharing rooms with younger colleagues.

As is specified in the DoA, a sensor will be used from EAB member Senseair. Its sensor K33 LP T/RH, pictured in Figure 16, combines all three measures and is the most likely to be chosen; although eventually another Senseair sensor may result more adequate. In case the illumination sensor will be a custom designed device (see previous section), this sensor will probably be integrated in the same device, using the same data connection with the WA Tool.

Figure 16. Senseair K33 LP T/RH: Combined temperature, relative humidity and CO_2 sensor.

2.5 Location data

2.5.1 Context

Location data have a specific role in the WA Tool since it will not be used to analyse the user strains as other sensors will. The location information will be used for the following purposes:

- Provision of the position of the different sensors at stake in the WA Tool.
- Provision of the user position to the emergency centres or PSAPs (Public Safety Answering Point) in case of emergency.

Two main categories of sensors have been identified in the D2.1 deliverable: *individual data* that are linked to a specific user, and *environmental data* that potentially concern several individuals and are locally valid. Thus, the definition of the use cases will strongly impact the location system infrastructure. For instance, the use case *'Office Worker'* could either put at stake a user that stays at his desk or a user potentially moving inside the building. Thus, the position of individual and environmental sensors would not be always the same. On the contrary, if the use case specifies that the user is staying at his desk, information of only one position datum may be needed and this would be the one of the desks. The *'Production Worker' and 'Driver Worker'* raise the same questions, even if the situation is the opposite: in this use cases they may be no static sensors and only mobiles one. So, as long as the use cases are different, the proper architecture for the location sensors will be defined accordingly. Next section will analyse potential location systems to be implemented in the WA Tool.

2.5.2 WA Tool location system

2.5.2.1 WA Tool location system requirements

We will take as hypothesis that there is a potential need for dynamic localisation for all the use case.

Table 2 summarises the location system requirements by Use Case.

Table 2. Location system requirements by Use Case

Requirements	Indoor/Outdoor positioning	Position rate	Accuracy	Size	Weight	Wireless	Power supply
U.C. Office							
Static system	Indoor	Fixed	Room size	No constraints	No constraints	No	No constraints
Mobile system	Indoor	1 Hz	Room size	Small	Light	Yes	Battery
U.C. Driver							
Static system	Both	1 Hz	10 meters	No constraints	No constraints	No	Cigarette lighter compatible
Mobile System	Both	1 Hz	10 meters	Small	Light	Yes	Battery
U.C. Production							
Static System	Indoor	Fixed	Room size	No constraints	No constraints	No	No constraints
Mobile system	Indoor	1 Hz	Room size	Small	Light	Yes	Battery

2.5.2.1.1 Use Case Office requirements:

Static system:

According to the requirements associated to the positioning of the environmental sensors installed in the office, relative location information like an office number or a floor number according to the architecture of the building would be adequate.

Mobile system:

The mobile location system shall be a light autonomous wearable system providing a 1Hz rate position. The required level of accuracy will depend on the definition of the Use Cases.

2.5.2.1.2 Use Case Driver requirements:

Static system:

The static location system shall be a dashboard-plugged system providing the vehicle location at 1Hz rate. The required level of accuracy will depend on the definition of the Use Cases. The system shall be able to provide both indoor and outdoor positioning in urban and rural environment.

Mobile system:

The mobile location system shall be a light autonomous wearable system providing a 1Hz rate position. The required level of accuracy will depend on the definition of the Use Cases. The system shall be able to provide both indoor and outdoor positioning in urban and rural environment.

2.5.2.1.3 Use Case Production requirements:

Static system:

According to the requirements associated to the positioning of the environmental sensors installed in the factory/depot, relative location information like a depot number or a production area inside the factory would be adequate.

Mobile system:

The mobile location system shall be an autonomous wearable system providing a 1Hz rate position. The required level of accuracy will depend on the definition of the Use Cases. The system shall be able to provide both indoor and outdoor positioning in urban and rural environment.

2.5.2.2 Location system preliminary study

Various location technologies and integrated products already exist and could be used for the WA project. This section will not provide an exhaustive presentation of available solutions, but only the one that could be considered at this early stage of the WA project.

2.5.2.2.1 GNSS

GNSS stands for *Global Navigation Satellite Systems* and it is the only global positioning method currently existing, i.e. the only positioning technology that can compute the user position anywhere on the planet. GNSS regroups all the satellite navigation constellations such as the American GPS, the European GALILEO, the Russian GLONASS and the Chinese BEIDOU. A GNSS receiver can track all these constellations at the same time and compute an accurate position based on measurements coming from all these systems together. In ideal conditions (open-sky), the GNSS receiver can reach a position accuracy of about 1 meter. However, GNSS is a technology based on satellite signals, so satellites need to be in view of the receiver for it to compute a position. Thus, in urban environments, the receiver can see less GNSS satellites and thus the GNSS position accuracy can drop down to 10 or even 100 meters in worst cases. In indoor environments, the receiver will not be able to track any satellite and therefore it will not be able to compute a position. Several augmentation techniques like RTK (*Real Time Kinematic*) or PPP (*Precise Point Positioning*) allow to increase the performances of the receiver. Most of them are based on the provision to the receiver of corrections data that are calculated by reference stations which position is perfectly known. These corrections can be either transmitted by satellites or by the Internet.

Figure 17 shows a GNSS module developed by Ublox and which could be integrated into the WA tool location system.

Figure 17. Ublox NEO-M8P GNSS module

Pros:

- Already widely used.
- No specific architecture required.
- Good precision in outdoor environment.
- Miniaturized GNSS chipsets available.

Cons:

- Outdoor positioning only.
- Degraded position in urban canyon.

2.5.2.2.2 Cell ID

Cell ID positioning is a network-based technique that rely on the signal transmitted by base stations. It is mostly implemented in handsets [109]. Each base station is sending out a unique ID combined with different parameters (e.g. mobile country code, mobile network code). A Cell ID database references the latitude and longitude of these base stations. While receiving the ID of a base station, the handsets search into the database the corresponding base stations.

Then the position of the handset is estimated to be within the area coverage of the concerned Cell ID. Cell ID positioning performance can be improved by measuring certain network attributes (e.g. Round-Trip Time between the base station and the user, Angle of arrival of the signal.

Pros:

- Indoor and Outdoor positioning.
- Already widely used.
- Architecture already deployed.

Cons:

- Kilometre-accuracy.

2.5.2.2.3 Wi-Fi

Wi-Fi technology is the WLAN (*Wireless Local Area Network*) technology that has gained the greatest success due to its low cost, widespread diffusion and robust communication capabilities, even in non-Line-of-Sight conditions [110]. Each Wi-Fi access point, whether customer hotspot, router or Internet-capable point of sale system, transmits specific data encompassing a MAC address (*Media Access Control*). An application can calculate the current location of the end user device using the fingerprinting method, i.e. received signal strength measurements from multiple Wi-Fi access points. During an offline phase, fingerprints are collected at known positions in the building. This database of locations and the associated fingerprints are called the radio map. In the online mode, the current Wi-Fi fingerprint probability distributions are compared with those of the radio map. The user location is estimated by calculating a weighted average of the offline positions that best match the online measurements. The accuracy depends on the number of nearby access points whose positions have been entered into the database.

<u>Pros</u>:

- Indoor and Outdoor positioning.
- Infrastructure already deployed in urban environment.
- Can reach good accuracy level [111].

<u>Cons:</u>

- Lack of infrastructure in rural environment.

2.5.2.2.4 Ultra-Wide Band

UWB (*Ultra-Wide Band*) is an emerging technology in the field of indoor positioning that has shown better performance compared to others. UWB is based on transmitting extremely short pulses and uses techniques that cause a spreading of the radio energy (over a wide frequency band) with a very low power spectral density. This high bandwidth offers high data throughput for communication. The low frequency of UWB pulses enables the signal to effectively pass through obstacles such as walls and objects [112]. UWB provides real-time indoor accurate positioning by utilizing the time difference of arrival (TDOA) of the RF signals to obtain the distance between the reference point and the target.

<u>Pros:</u>

- High accuracy positioning.

<u>Cons:</u>

- Emerging technology.
- May not be available as requires specific architecture.

Figure 18. Eliko UWB positioning system

2.5.2.2.5 RFID

Radio Frequency IDentification, or RFID, is a low-cost, practical way to identify and keep track of almost anything -- from wildlife to goods in a warehouse. The technology centres on electronic "tags" which store data and respond to a radio frequency reader device. The reader's signal instantly triggers the tag (transmitter), which transmits its data. RFID tags use no power and cost a few pennies each [112].

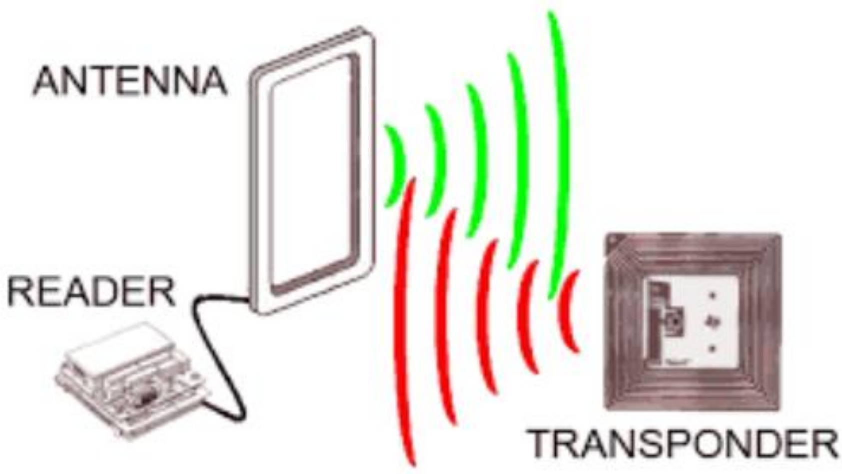

Figure 19. RFID principle

Many companies use RFID tags to track the flow of goods through warehousing, distribution and retail. In the case of recycling, they can even track goods returned. Security companies place tags in access cards. A reader detects the card's presence in your pocket and automatically unlocks doors and turns on lights [112]. In our case, we could use the chips to detect in what room or in front of what machinery the user is located. Then the room or machinery will be related to a position that we would match the user with.

2.5.2.3 Potential integrated products for location

2.5.2.3.1 Smartphones

Since the user interface will be provided via a smartphone/tablet application, the WA Tool requires the use of a smartphone.

Nevertheless, in some cases, it remains unsure that the user will always be able to have his smartphone on him, notably for the manufacture use case. Therefore, we will not be able to always use a smartphone as positioning device.

Most smartphones currently hold a GNSS receiver chipset and use Wi-Fi to improve positioning accuracy by computing a fused GNSS-Wi-Fi location. Most of the major brands that share the European market now only develop Galileo compatible smartphones (e.g. Apple, Samsung, BQ, Huawei, and Xiaomi).

Moreover, the emergency call feature of the WA Tool may be based on the use of AML (*Advanced Mobile Location*). As AML is already natively implanted in Android OS since Gingerbread version 2.3.7, an Android smartphone equipped with a SIM card providing voice and data would be a good candidate as the location system of WA Tool, assuming that Use Cases have defined that this smartphone shall stay on the user the whole time.

Table 3 provides examples of smartphone that could fulfil the mission.

Table 3. Potential smartphones for WA Tool.

Smartphone	Chipset	Price (euros)
Samsung - S8	Exynos 9 Octa 8895	Around 380
Samsung - S9	Exynos 9 Octa 9810	Around 700
Xiaomi - MI8	Qualcomm Snapdragon 845	Around 500
Apple - iPhone 7	Apple A10 fusion	Around 530

2.5.2.3.2 Smartwatches

Smartwatches could be used in the WA Tool in standalone or as an accessory to a smartphone. Indeed, some smartwatches embed a SIM card and some do not. The chosen model shall embed a GNSS chipset and have a SIM card for the standalone architecture. Compared to a smartphone, the watch would have the advantage of being lighter, and fixed at the wrist of the user. For the standalone architecture, a wearable application will have to be developed. But the smartwatch may not be able to fulfil all the WA missions, which are computing and transmitting the user’s location to the WA Tool in real time. Moreover, very few smartwatches seem to be Galileo compatible at the moment. For instance, Samsung Galaxy Watch E-Sim 4G is not compatible with Galileo, while Apple Watch series 3 is. And most of them only provide location using GNSS (which is not efficient indoor).

Figure 20. Apple watch displaying the user location.

Table 4. Potential smartwatches for WA Tool

Smartwatch	Location techno.	Sim card	Price (euros)
Apple - Watch Series 3	GPS, GLONASS, Galileo, QZSS	Yes	400
Samsung Galaxy Watch E-Sim 4G	GPS, GLONASS, QZSS	Yes	380
Samsung - Galaxy Watch Active	GPS, GLONASS, Galileo	No	230
Garmin - Foretrex 601	GPS, GLONASS, Galileo	No	250
Garmin - Instinct	GPS, GLONASS, Galileo	No	300

2.5.2.3.3 Smart Soles

Some smart soles embed location systems to provide more security to workers. For instance, the TRAXxs solution [113] fuses location information coming from GNSS (GPS & Galileo) as well as Bluetooth position based on the use of beacons to be installed inside the buildings. The system provides a configurable alert transmission system (by SMS, email and notification) and can work in standalone mode or connected to a smartphone. This kind of system could be used in the WA Tool by bypassing the communication between the smart sole and the control centre to get the location data and provide it to the WA Tool. Nevertheless, we cannot use the smart sole as a standalone equipment, it shall be complementary of a smartphone or smartwatch.

Figure 21 shows the TRAXxs smart sole solution.

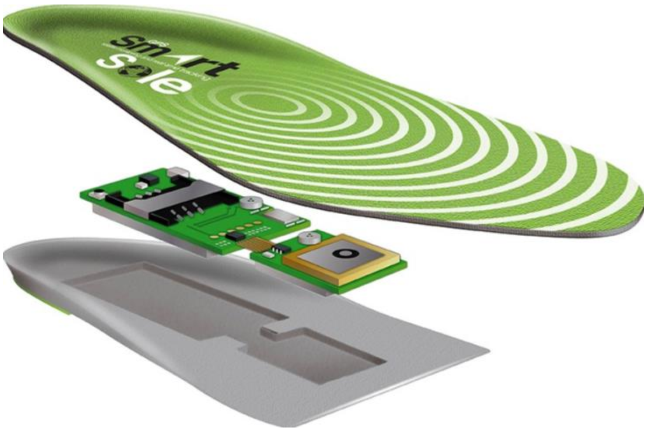

Figure 21. Smart Sole solution by TRAXxs

2.5.2.3.4 Trackers

A large variety of trackers appeared on the market for several purposes: tracking of assets, people or vehicles. For instance, it would help to find someone suffering of Alzheimer who would have lost his way home. Moreover, most of these trackers embed an alarm system that send it to a particular or to a control centre. These trackers can be embedded in various objects like key rings, soles (see previous section) or a small device to be kept inside a pocket [114]. Some of these trackers are GNSS only or combine GNSS, Cell ID and Wi-Fi technologies. Most of these products are delivered with an application to install on a smartphone and transmit data to a private server. So, it may be impossible to catch the data flow coming from the tracker and thus to use them in the WA Tool. But it could be considered to develop this type of tracker for the need of WA Tool. The following section deals with this solution.

Next picture shows an example of such trackers (made by SOS Buddy).

Figure 22. GPS Tracker

2.5.2.3.5 Self-made tool

Instead of using an already integrated solution, a self-made solution could be developed by TPZF. This solution shall at least implement:

- A Galileo compatible GNSS chipset.
- A microcontroller unit.
- A Wi-Fi module.

Additional functionalities could be embedded, like:

- UWB positioning.
- Bluetooth.
- RFID

The Wi-Fi module shall provide indoor positioning and could be responsible for communication with the WA Tool sensors and global cloud.
Table 5 provides examples of chipset that we could use in the self-made tool.

Table 5. Examples of chipset for the self-made tool.

Chipset	Type	Price (euros)
Ublox - SAM-M8Q	GNSS	12 euros (more than 100 pcs)
Qualcomm - SiRFstar V 5e	GNSS	On demand
STMicroelectronics - STM32L1	MCU	15
Raspberry PI 3	MCU	30
STMicroelectronics – SPWF01	Wi-Fi	On demand

The Raspberry PI embeds a Wi-Fi module and could also be used to develop an UWB positioning solution.

Figure 23 shows a Raspberry PI model 3, that could be used during the WA Tool location system development.

Figure 23. Raspberry PI MCU

2.5.3 Section Conclusion

In the most demanding use case, the location system shall:

- Provide indoor and outdoor positioning
- Work even in urban canyon environments

GNSS is able to provide outdoor positioning, with good accuracy in open sky environments. In urban canyon environment, Wi-Fi can be used to provide location. A fused location (GNSS/Wi-Fi) can thus be computed. Moreover, Wi-Fi can provide indoor positioning. A GNSS and Wi-Fi location technology can thus be taken as a basis for the WA Tool location system. Additional technologies could be integrated according to the targeted level of accuracy (defined by the use cases). Several devices intrinsically provide a location calculated using a fusion of the technologies described in the previous paragraph. Next section aims at shortly presenting potentially interesting devices to be used in the WA tool location system as standalone solutions or combined.

Regarding illumination, of the three proposed approaches, the mobile APP shows itself as the less suitable for the WA Tool, due to its low performance and accuracy limitations. The custom developed solution, while technically viable, would imply a highly complex and costly development to obtain accurate calibrated sensors. Commercial luxmeters, on the other hand, overcome the limitations of both previous approaches regarding accuracy, performance and development complexity. However, they may present some challenges regarding their integration within the WA Tool, such as proprietary interfaces, access to raw data, configuration limitations, etc.

If the commercial devices cannot be integrated directly in the WA Tool, a combination of a custom developed solution and commercial devices could bring together the advantages of both approaches and surmount the limitations they present. This approach could make use of commercial sensors from lux meters or lux meters to obtain accurate calibrated measurements that will be gathered and processed by means of the necessary custom developed interfaces.

3 Technology Selection

On the basis of the VDI guidelines "*Technology Assessment – Concept and Foundations*" [115] and the requirements defined in Deliverable D2.1, the following criteria will help to select the appropriate technology for the development of the WA Tool:

- FUNCTIONALITY:

  The technology must be selected to meet the requirements in terms of functionality. The functionality of a technology consists in being capable of bringing desired effects under specified conditions, and it is usually measured in terms of speed, power, capacity, etc. These effects should be as strong as possible (*effectiveness*). In its structural design and performance, a well-functioning technological system stands out for being as simple, robust, precise, reliable, long-lived, etc. as possible (*perfection*). These qualities must be balanced with one another. Finally, one of the principles of technical design is to maximise the ratio of output to input, e.g., concerning energetic efficiency, yield of material, or quantitative productivity (technical efficiency).

- ECONOMY:

Technical decisions are subject to the dictates of thrift due to the unavoidable shortage of resources that are necessary to create and use technological systems (e.g. materials, energy, labour power, means of production, etc.). What is relevant here is the value of economy, i.e., the principle of economic rationality. The price will play a second role compared to the devices' functionalities. The consortium will not select the best of the cheapest products: the equipment will be selected after function, choosing the best price of those devices fulfilling all the technical requirements.

- USER CENTRIC DESIGN:

In general, the experimental equipment will be chosen following the user centric approach: the smart devices and sensors will be compliant with user's working activity, in order to do not interfere within the daily activities. The devices and the software algorithms will be regulated to evaluate the user physical and mental condition. The user will be engaged since the first phase of the pilot test: each block of the experimental design will be designed to interact with the user.

- SAFETY & HEALTH:

Safety in the development and use of technology means the absence of dangers to life and health. Safety standards refer to freedom of bodily harm. Three types of risks can be distinguished. *Operating risks* refers to the damage that can arise with trouble-free operation and appropriate use of the technological system in question. *Failure risk* refers to damage that can occur in case of a breakdown. *Misuse risk* refers to damage that can arise from inappropriate use of the technology. Thus, apart from minimising operating risk and failure risk, there is an additional safety requirement to eliminate the possibility of inappropriate use to the extent possible by technological and other means. The term *Health* means the condition in which individuals enjoy physical and psychological well-being. This is expressed not only in objectively ascertainable factors but also in the perception that each person has of himself or herself. Health is manifested in psychophysical resistance, i.e., in the capacity to react appropriately to internal and external stress. Individual and general feelings of health and illness are relative, tied to different times, environments, and cultures. For example, the achievements of health technology have led to higher standards of well-being.

The danger related to a high electromagnetic field during the experimental session has been considered but, given that no scientific proof exists that these waves would be dangerous and that there is no significant difference compared to a normal office environment (in which you have several PCs and devices), no provisions has been taken in this direction.

On the basis of these structures, the inclusion criteria for the WA Tool definition have been identified by asking the partners to fill a survey on the basis of the following definitions:

1. This criterion is *absolutely necessary*, i.e. if the sensor does not meet this criterion it is not usable for the WorkingAge project (K.O.-criterion).

2. This criterion *is possible, but not absolutely necessary* for the WorkingAge project (nice-to-have).

The questionnaire was structured as follows (Figure 24):

	Criteria for Technology Selection	K.O. criterion	nice to have
	Technical Specifications:		
	Measurement validity regarding required type of strain, stress or environment influences (e.g. mental, physical, emotional)	☐	☐
	high signal stability	☐	☐
	high frequency	☐	☐
	record data quality	☐	☐
	Please add missing criteria	☐	☐

Figure 24. Extract of the questionnaire to define the requirements of the sensors.

The analysis considered all WorkingAge use cases together, so that, in the ideal case, there would be at least one sensor that could cover all K.O.-criteria. If there is no suitable sensor, which fulfils all determined criteria, a sensor should be selected that fulfils as many of the K.O.-criteria as possible. The following table gives a quantitative statement about which criteria were defined as K.O. criteria in the survey (Table 6). The Survey was answered by nine partners. In order to be able to work out the most important criteria, a threshold is defined. Only those criteria will be selected which have been considered as absolutely necessary by at least two-thirds of the partners (min. 6 nominations). The following Table 6 illustrates the results of the survey. The number of nominations as a K.O-criteria is shoen. The *Conclusion*-section illustrates these criteria, which have reached the two-thirds majority.

Table 6. K.O.-criteria for technology selection.

	K.O.-criteria ***Number of nominations***	***Conclusion***
Functionality		
Measurement validity regarding required type of strain, stress or environment influences (e.g. mental, physical, emotional)	6	**x**

High signal stability	3	
High frequency	2	
Record data quality	7	**x**
High graphic capabilities (Smartphone)	1	
Wireless communication with local cloud	1	
No redundancy in sensors	1	
Wireless signal processing	1	
Compact design (small & light)	2	
Battery power source (autonomous system)	2	
Placeable in the cockpit of a vehicle	8	**x**
Placeable in an office workplace	9	**x**
Placeable in an production workplace (for example when handling with workpieces)	8	**x**
The sensor should be adaptable to different environmental conditions…	3	
Robust to different illumination conditions	4	
Robust to different temperature conditions	3	
Robust to vibrations	2	
Robust to different noise conditions	3	
Robust to occlusion problems	2	
Robust (e.g. dust, dirt, humidity)	2	
Economy		
Low price (cost-benefit analysis)	0	
Reliability	8	**x**
Safety & Health		
Non-disruptive	2	
Non-intrusive	5	
In accordance with occupational safety and health regulations	7	**x**

3.1.1 Section Conclusion

In Table 6, we can see that only a few technological criteria received an "**x**" in their conclusion column. This is due to the fact, that in order for a technological criterion to be considered as K.O., it had to be approved by at least two-thirds of the partners and was only then classified as *absolutely necessary*.

This means that the technology selection should therefore address:

- *Measurement validity;*
- *Record data quality;*
- *Placeable in the cockpit of a vehicle;*
- *Placeable in office workstation;*
- *Placeable in the production workplace;*
- *Reliable;*
- *In accordance with occupational safety and health regulations.*

4 General Conclusions

Within the experimental WA study, the oculo-motive parameters are tested and examined for their suitability for application. Due to the different use cases, different parameters could be suitable. Therefore, an eye-tracking device is to be tested in laboratory studies, so that parameters could be adjusted depending on the results. The interview to define the requirements for the HCI solution should identify unknown requirements that are considered relevant by the users. In this case, focus groups can be used. To collect feedback and to evaluate the WorkingAge Tool a questionnaire is particularly useful.

Section 2.4.3 provides an analysis of available options, based on the most common and accurate light measurement technologies that could be used for illumination measurement within the WA Tool. The results of these available options display three different possible approaches, as well as their advantages and their disadvantages: smartphones and mobile APPs, commercial lux meters, and custom developed solutions. In conclusion, the most suitable potential solution regarding illumination would be a combination of commercial sensors or lux meters and the development of specifically designed devices if the limitations of the commercial devices require so. This solution would comprise commercial (phototransistor or IC based) lux meters or lux meter sensors, and specifically developed devices to provide interfaces (e.g. wireless communication, sampling configuration, etc.) and signal processing between the commercial devices and the WA Tool, if needed.

As we have been commented before (Section 2.3.1) there are several options in order to estimate the body pose of the users, but the most suitable of them is to use a 2D camera to obtain 3D information regarding the location of the most significant parts of the body (head, shoulders and so on). The main advantages of using a 2D camera as a sensor are that cameras are a non-intrusive sensor and their reduced cost. Consequently, 2D cameras are the best option to be used in the WA tool and will therefore be tested in the laboratory and pilots test.

In the following table a summary of the potential sensor solutions and their corresponding estimated price per subject are provided (note the remarks on Economy in section 3):

Table 7. Sensor's price estimation.

Sensor	Potential solution	Estimated price
EEG + EOG	Live Amp + Solid gel electrode	10.000€
ECG	Empatica E4	2.000€
Voice recognition	Sennheiser CC 510 + Jabra 510	200€

Pose	Wi-Fi IP Camera	100€
Facial recognition	2 x Wi-Fi IP Camera	120€
Location		1.000€
Eye-tracking	Tobii Glasses 2	20.000€
Illumination	Luxmeters	300€ - 400€
Gesture recognition	Wi-Fi IP Camera + NDIVIA GPU + software + smartphone / tablet	2.000€ - 3.000€
IoT	Green PI units	600€ per unit
Thermohygrometric and CO2		57€

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