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D6.2 Human Factor Measurement Toolkit

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Versions

Vers.	Date	Author	Description
V0.1	18/02/2021	Helmut Schrom-Feiertag (AIT)	First Draft
V0.2	22/03/2021	Helmut Schrom-Feiertag (AIT), Bruno Gardlo (AIT)	Additions and detailed outlines of the data management system
V0.3	05/04/2021	Helmut Schrom-Feiertag (AIT), Markus Murtinger (USE)	Version sent out to the consortium for peer-review
V0.4	13/04/2021	Helmut Schrom-Feiertag (AIT), Quynh Nguyen (AIT)	Integration of feedback from partners and internal meeting for quality assurance
V0.5	27/04/2021	Helmut Schrom-Feiertag (AIT), Quynh Nguyen (AIT), Markus Murtinger (USE)	Final review and finalisation of the document
V1.0	30/04/2021	Markus Murtinger (USE)	Version submitted to the EC

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List of Acronyms and Abbreviations

Acronym / Abbreviation	
ECG	Electrocardiography
EDA	Electrodermal activity
EEG	Electroencephalography
ER	Entity relation
FEA	Facial expression analysis
GSR	Galvanic skin response
HF	Human factors
HRV	Heart rate variability
LEA	Law enforcement agency
PPG	Photoplethysmogram
VR	Virtual reality
WP	Work package

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1 Executive Summary

Based on the identified psychological, experiential constructs to be measured during the Human Factor (HF) studies in Work Package (WP) 6, the Human Factor measurement toolkit comprises tools to collect qualitative and quantitative data through measurement instruments such as questionnaires, physiological measures, log data from the developed VR system as well as target achievements during the execution of given tasks. Where existing measurement instruments do not suffice for our aims, we either develop novel assessment methods or extend existing ones.

Furthermore, the document defines the tools used to analyse the data collected and thus serves as a basis for all researchers involved. Thus, the measurement suite consists of 3 core elements: (a) the development of an online based tool for data collection and data sharing between the involved partners, (b) a collection of the used tools for data collection and (c) the short description of the used tools for data evaluation and analysis. The current document (D6.2) describes the different data sources, data formats and data storage and linkage planned to be utilised for the preparation, conductance, and analysis of the Human Factor studies. Due to the agile approach adapted in SHOTPROS, the deliverable forms the basis of our data concept. It will be continuously adapted as needed (e.g. based on new findings or needs emerging from the studies).

The HF measurement toolkit pursues the following concrete objectives:

- Definition of the data measurement tools used for the individual HF studies.
- Definition of the individual data sources and which data (a) are used for the analysis in WP6 but also for later use in the VR system (e.g. for D4.5 the live dashboard).
- A collection of the used data analysis tools.
- Efficient evaluation of the different data sources of the individual HF studies (see D6.1) and the possibility of linking the data.
- Technological architecture concept for storing the data to enable later analysis (D6.3).
- A basis for the development of a machine learning approach based on the generated data sets and links (D6.4).

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2 Overview and introduction

In the following, we provide an overview to the (current) data sources collected during the Human Factor Studies as well the data analysis tools utilised for the analyses thereof.

2.1.1 Data Sources

The following (current) sources were identified as data providers within the planned HF Studies (see D6.1).

- Physiological and bio data:
  - Heart rate and heart rate variability (HRV)
  - Respiration rate
  - Body temperature
  - Eye movements and pupillometry
  - Data from saliva samples:
    - Cortisol concentration
    - Alpha-amylase concentration
- Questionnaires such as
  - Sense of Presence Inventory (SOPI)
  - Visual analogue scales (stress thermometer, rating of mental effort)
  - Quality of Experience
  - Technology Acceptance Questionnaire
  - Quality of Learning
- Observational protocols during the HF Studies
- Transcripts from LEA Feedback Weeks (see D1.1.)
  - Logs and feedbacks
- Automated recorded data logs from the current VR system:
  - The data logs are the recorded data during the training sessions from the SHOTPROS VR training system which are used for the after-action review.
  - A subset with motion data and event information is exported for data analysis and based on new identified user requirements this subset will be revised. See Annex 1 for the full list.

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2.1.2 Data Analysis Tools

The following tools serve to support the evaluation of the data obtained from the HF studies. Depending on the subject area, different applications and tools are used to compare data (e.g. real-time stress) and to compare the evaluation results.

- Zephyr OmniSense (https://www.zephyranywhere.com/system/omnisense-software): This cloud-based software enables the analysis of key inputs from the Zephyr Performance Systems that report on more than 20 biometrics before, during, and after activities: This cloud-based software enables the analysis of key inputs from the Zephyr Performance Systems that report on more than 20 biometrics before, during and after activities.
- Kubios (https://www.kubios.com/): Kubios is a HRV analysis software for scientific research and professional use, featuring assets such as automated pre-processing of data (e.g. noise handling), automatic heart beat correction, more than 40 HRV analysis parameters and time-varying analysis.
- iMotions (https://imotions.com/): iMotions is an integrated analysis platform to conduct human behavior research. The iMotions software integrates and synchronizes multiple biometric sensors such as mobile eye trackers, mobile EEG systems, or VR headsets. It provides different human insight (e.g. eye-tracking or facial expression analysis (FEA)).

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3 Relation to SHOTPROS

This deliverable (D6.2) builds the foundation for further work in WP6 and facilitates the collaboration of the different researchers in this WP. It creates a data management structure and describes how the data is to be collected and shared within the SHOTPROS consortium. The subsequent analysis of the data (based on D6.3) provides direct requirements and impetus for the agile development and the backlog of the VR system, especially regarding the topics of stress display and training performance indicators. Qualitative inputs of the end users are collected in D6.2 and considered in the analysis and in the development as well.

Deliverable	Influence and expected outcome from D6.2
D4.5	The defined measurement suite (D6.2) and the analysis of the data (based on D6.3) will deliver relevant input for the visualization and interaction concept of the "Real-Time Training Progress Assessment Tool" (D4.5) for the VR system (such as dashboard functions and data structures, live view of bio signal data of the trainees, etc.).
D5.2	The results from analysing the data with the measurement suite will deliver requirements and insights for the agile development process (D5.2).
D6.3	The collected data from the HF studies (WP6) within the D6.2 will be prepared and structured within the D6.3 "Human Factors Study Transcripts and Log Files". Therefore, D6.2 creates the fundamental data structures and enables the planned steps.
D6.4	Within D6.4 (Human Factor Impact Analysis and Machine Learning Models) the structured data will be analysed and evaluated and a concept for machine learning models will be created. Therefore, D6.2 builds the fundament for this future work that aims to derive prediction models for DMA.

Table 1 - Influence and expected outcome of the D6.2

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4 Components of the Human Factors Measurement Toolkit

In the following section, the components of the HF measurement toolkit will be described in more detail. As an overview, the toolkit consists of three parts: the data sources, the data management, and the data analysis tools. As a quick overview, each of them entails the following:

Data Sources

- Questionnaires (among others, those used in the Zürich study, D4.4, included in this document in the Appendix)
- Data from physiological measurement tools
- Data in the RE-liON System

Data Management (collection, pre-processing, access)

- Collecting data in databases (questionnaires, physiological data, tracking, movement)
- Timestamps for data acquisition and synchronisation
- The data are organised in a hierarchical order by training sessions that refers to trainees that did the training and each trainee refers to a set of data collected from different sources. Information on the trainees are pseudonymised
- Algorithm library (pre-processing, analysis)
- Import / export functionality

Data Analysis Tools (current selection)

- Kubios HRV software
- OmniSense
- iMotion

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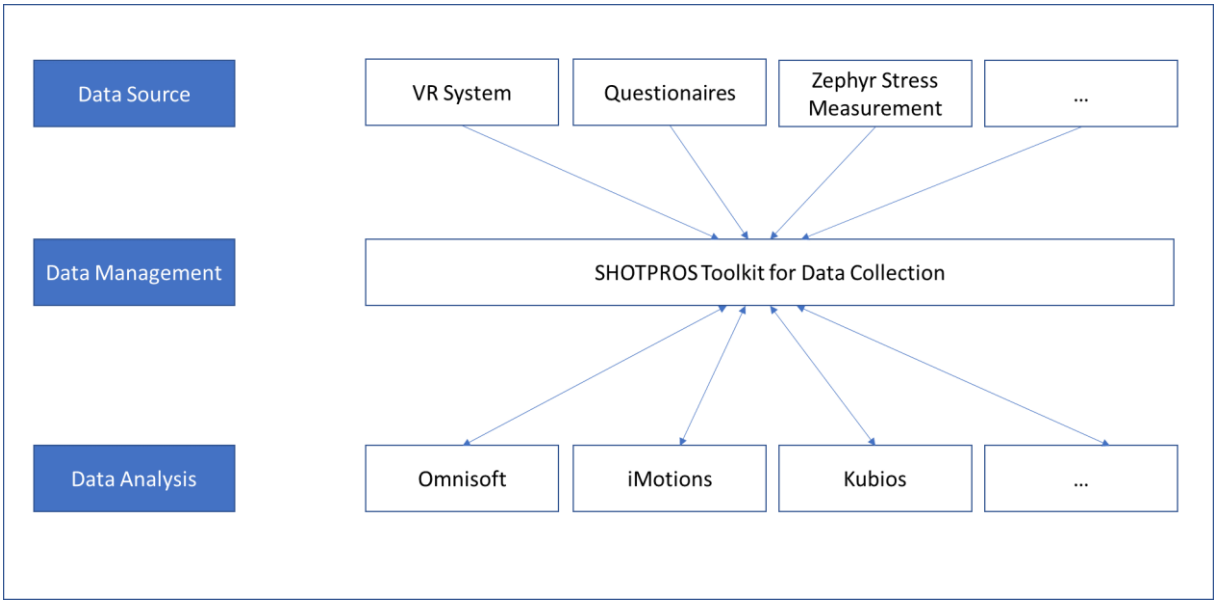

Figure 1: Visual representation of key elements in D6.2, broken up into the three main categories: data sources, management, and analysis.

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4.1 Relation of the HF Studies

This document provides the data sources and measurement instruments, the data structure management, user interface and assessment methods for the HF studies conducted in WP6 (see D6.1). In the HF studies, investigations are carried out with the VR training system in order to obtain findings on the design of training scenarios and the augmentation with stress cues, the design of components of the VR system such as the dashboards for After-Action Review and real-time stress measurement, the effects of the VR training system on individuals, on the training outcomes, as well as implications on VR training from the perspective of training curriculum development.

To this end, we will briefly define the research questions to be answered in the studies:

- To which extent do the functionalities of the currently developed VR system (particularly the trainer interface and the technical set-up and handling of the system) in SHOTPROS fulfill the initial requirements from WP2 from the end user perspective? What needs to be improved?
- Which of the stress cues developed in WP4 can induce stress in users of the VR system (based on physiological and behavioural measures as well as quantitative and qualitative self-assessments) in isolation? How does this change when introducing confounding factors such as environment (indoor/outdoor) or weather conditions? To which extent can the inducement of stress be strengthened or weakened by combining stress cues in training scenarios?
- How do realistic training and VR training compare in terms of logistics, e.g. with regard to training times, executed repetitions, used variations in a scenario and difference in required feedback? How do they differ in terms of learning experience and induced stress levels?
- How can stress be best measured in real-time to support DMA-SR training? How can stress data best support the training? To this end, the following sub research questions will be addressed:
  - Does the data quality differ between different biosensors (e.g. the Zephyr BioHarness 3 and Garmin Fenix 6 Pro system) for heart rate and respiration rate data?
  - Are there any user experience or usability issues in using these both systems (belt slippage, hygiene issues, wearing comfort, etc.)?
  - How does the internally calculated stress score from different analysis software tools (e.g. Omnisense, Garmin software, HP Reverb 2 software) differ from each other? Can it be used, adapted or reproduced for our system?

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- Which hardware is best suited for later implementation and use in the SHOTPROS VR system?
- What data should be made available to the trainer in the live view or after-action review (based on the data analysis and quality of the data)?
- Are there correlations between the data of the individual systems or are they valid and reproducible?

The gathered results will then be transfers to development backlog and formulated as requirements for the VR system.

4.2 Data Sources and Measurement Instruments

As shortly described in Section 2, data within the HF studies are collected through the Zephyr Stress Measurement Tool, saliva samples, questionnaires, observational protocols, transcripts, as well as automatically recorded data logs from the current VR system. In the following, we will describe the physiological data sources as well as the used questionnaires in more detail.

4.2.1 Data Sources for Physiological Stress Measurement

The topic of stress measurement and visualisation of the current status is a central undertaking in the project and will therefore be given special consideration in the planned HF Studies. In the current literature, stress is usually analysed over a longer period of time (e.g. one hour, one day, etc.) and there is little evidence for live stress measurement, which is highly relevant for our project. Following the previous deliverables and results, the term stress in SHOTPROS is defined as follows (see D3.2): *The emotional response of a trainee to an event that is appraised as threatening (as opposed to irrelevant or benign) to well-being and in which the trainee perceives limited coping possibilities or control.* We can never be sure if a stress cue is appraised as threatening to well-being and is perceived as out of control. We can increase the likelihood of that happening, by introducing cues that are typically perceived as threatening and uncontrollable. Therefore, to support the trainers in this topic and to see direct changes regarding the stress level, the stress measurement in real-time is essential. The planned research experiments during the HF studies will deliver insights how to handle this issue and deliver the input for the development and design of the real time dashboard with the visualisation for the stress topic (stress scoring, threshold and/or stress indicators).

Therefore, in the course of the D6.2 development and previous results (e.g. D4.3), we defined the relevant research questions (see Section 4.1) and the appropriate setup of hardware and

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software to provide the concrete inputs for the agile development and the components for the integration into the future VR system but also for the usage in real-world training.

Physiological Measurement Hardware

The following hardware components were selected and will be evaluated during the planned HF Studies. The objective is to compare the hardware and to see the correlation of the measured data. Based on these data, the end user requirements and the expert inputs, we will define the requirements for the VR System (within the D4.6 for Scenario Requirements and D5.4 for the VR results dashboard and Measuring Training Sessions) and this hardware will be implemented:

- **Zephyr BioHarness 3**: A wireless professional heart rate & physiological monitor chest strap. Measures:
  - Heart rate and heart rate variability (HRV)
  - Respiration rate
  - Body temperature
  - Body movements
- **Garmin Fenix 6 Pro**: A wireless smart watch which measures
  - Heart rate
  - Respiration rate
- **(Experimental) HP Reverb Omnicept G2**: A head-mounted display which can measure:
  - Eye movements and pupillometry
  - Heart rate
  - Facial expressions
- **Recorded data in the actual BLUESUIT VR system**:
  - Trainee position data
  - Body movement data from the smart vest/suit
  - Usage of tactical objects (e.g. pepper spray, gun, etc.)
  - Trigger/events (e.g. opening doors, light on/off, etc.)
- **Additional bio data from saliva samples:**
  - Cortisol concentration
  - Alpha-amylase concentration

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4.2.2 Questionnaires for the HF Studies

Different studies and different questionnaires are used to answer these different research questions. Table 2 lists the questionnaires that are used in the studies. Wherever possible, these questionnaires will be completed digitally (i.e. on a laptop or tablet) for ease of analysis through survey creation tools such as LimeSurvey, SosciSurvey or similar tools.

Table 2: Current list of questionnaires used in the HF studies.

Instrument / Construct	Experience Dimensions	References
Sense of Presence Inventory (SOPI)	Presence Immersion Realism	Lessiter et al. (2001)
Quality of Experience (QoE) & User Experience (UX)	Perceived quality Pragmatic aspects Hedonic aspects Eudaimonic aspects	Möller & Raake (2014), Hammer et al. (2018), Hassenzahl et al. (2008)
Technology Acceptance (TAC)	Ease of Use Usefulness Intention to use Imagination Immersion Interactivity Enjoyment	Vekantesh & Bala (2008), Huang et al. (2013)
Visual Analogue Scales (VAC)	Experienced stress Mental exertion	Houtman & Bakker (1989), Zijlstra (1993)
Quality of Learning Experience (QoLE)	Self-Efficacy Assessment	Kirkpatrick & Kirkpatrick (2006)

Additionally, the Attrakdiff, Eudaimonic and VRQoE (alternative for SOPI) questionnaires are seen as further possibilities.

Questionnaires used by Zürich study (see D4.4) are included in the Appendix of this document.

4.3 Data Management

Through the data management, we present a technological architecture concept for storing the data to enable later analysis, including interfaces to import and export data to and from the database for a variety of data and formats from questionnaires to physiological data streams and BLUESUIT data.

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4.3.1 Data Model

The first step towards creating a database management system is to design a simple entity-relation (ER) diagram in order to have a clear picture of the database and its contents. A data set for a study comprises:

- Training sessions
  - Trainer: who is supervising the training and doing the afteraction review
  - Trainee: each session consists of one or more trainees with some meta data. Each trainee has data associated from different sources like:
    - Questionnaire data
    - Physiological measurements
    - BLUESUIT logging data
    - Analysis and assessment results

The database schema therefore contains five entities: Trainee, Trainer, Training Session, Questionnaire and Files. Each of these entities has certain attributes and an ID in order to be unique, while relations connect certain entities. The design of the ER diagram can be seen in Figure 2.

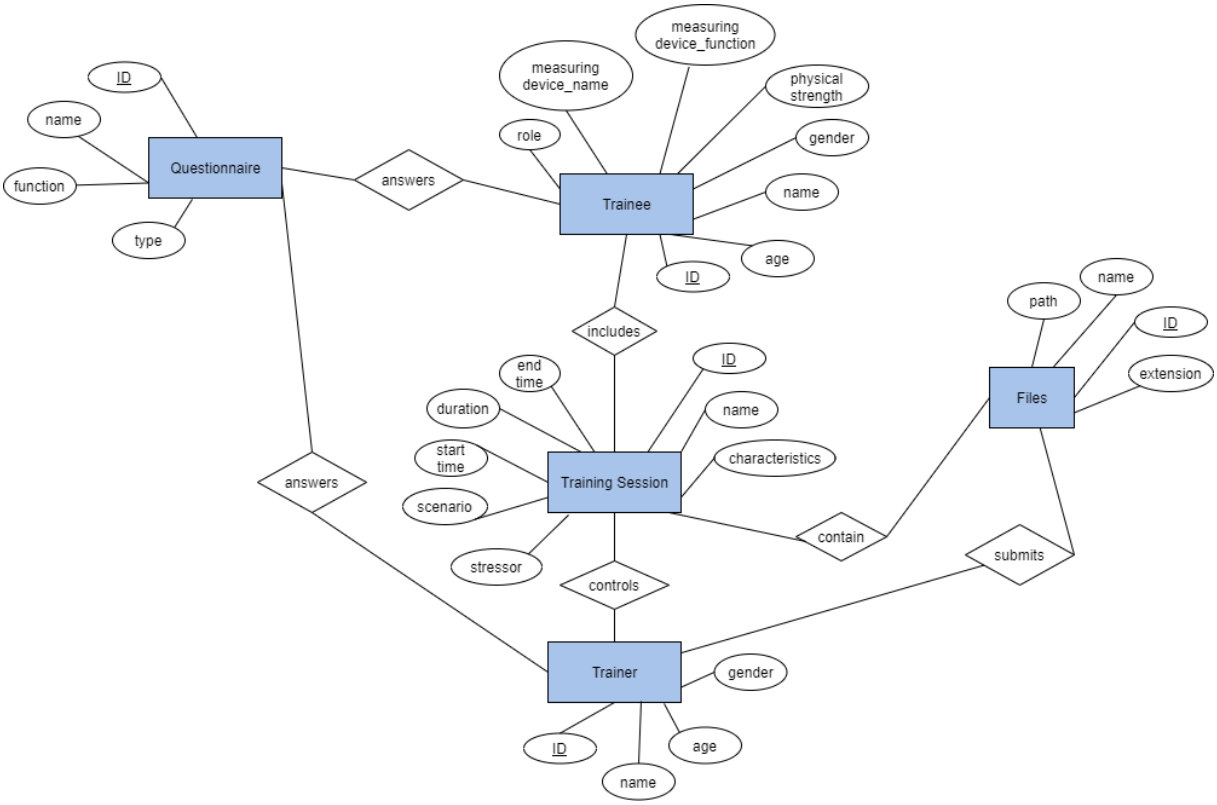

Figure 2: Entity-Relation Diagram

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Very important is the synchronisation of the different data sources to provide the same time base to be able to investigate events and reactions. This synchronization cannot always be performed at the time of data collection. Thus, it is necessary to have this feature available at the time of data collection and storage. If there does not exist any external event in-between different data sources, which can be used for synchronization, then it will be possible to specify such event in a data management tool later on when the data are uploaded to the data management system.

4.3.2 Technological Architecture

The purpose of the data management system is to ensure a unified way to store data from different systems and sources. The system must be capable of processing data from different sources as described earlier in this deliverable. For this purpose, a backend server with several different micro-services is developed and orchestrated with the Docker Engine[1], an open source technology for building and containerizing applications. Containerizing the whole server structure into microservices offers great scalability and using Docker offers easy deployment and portability to different physical servers, if needed.

The core of the back-end system is a NodeJS application build with the Koa.js framework. NodeJS offers high throughput of data and very high performance in comparison to other existing server technologies (e.g. Java, Python, PHP), which will be crucial when processing large amount of data by several users at a time. This core micro-service is responsible for data reception from front-end application (described later in the document), organising workload among different services, each responsible only for a single task, and establishing unique folders and file structures so that the uploaded data are stored in a reasonable and human-readable structure. The core microservice is also responsible for connection and create, read, update and delete (CRUD) operations to the actual database which runs on MySQL.

Single feature tasks can be described as tasks responsible for processing and storing the data from physical measurements, VR system or service responsible for binding questionnaire data from multiple users to each training session and the respective trainee. There are separate microservices responsible for data upload and export. The structure of the database management system can be seen in Figure 3. In case there is a need for a new feature, exporting pipeline or presentational API, it can be done by creating a new container with microservice.

[1] https://docs.docker.com/engine/

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Microservices are designed to be independent of each other and can run on different underlying technology. Core services and basic microservices described earlier in this section are designed to be written in plain JavaScript and deployed in the NodeJS server running behind the Nginx reverse proxy. Any microservice responsible for data export can utilise any of the well-known technologies, e.g. Python with Pandas, or R. It should be specified later what the needs for data analysis and machine learning inputs are and to design microservices which will support such needs.

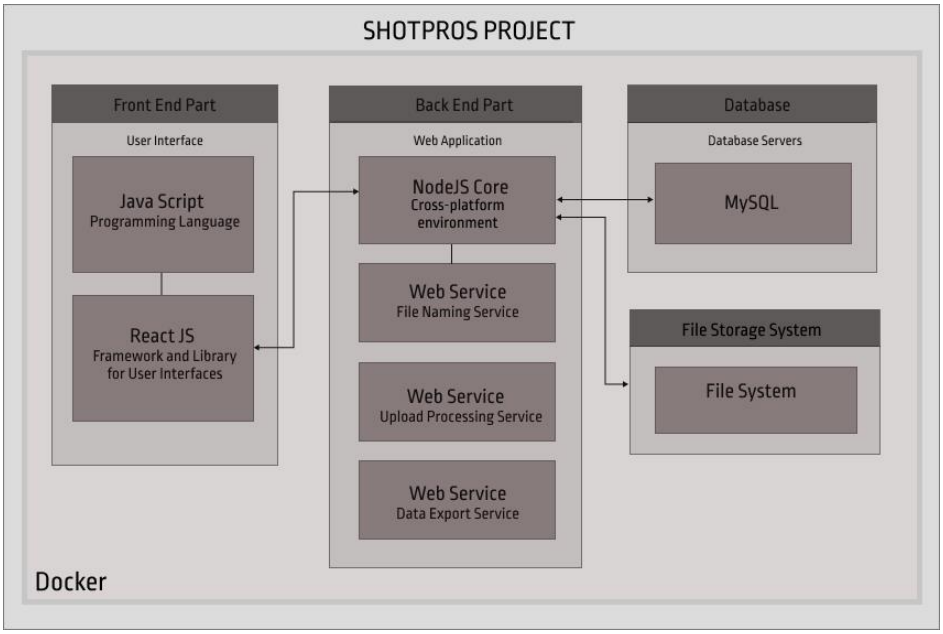

Figure 3: Database management system structure

To offer an easy way to work with the back-end API and service, we are designing a front-end application in JavaScript and build by utilising ReactJS framework together with Material UI elements. Utilising JavaScript programming language on both front-end and back-end offers better maintainability to the future and saves valuable time during the development phase. All frameworks used in the project currently represent state-of-the-art technology and full stack system designs.

4.3.3 User Interface

The web front-end for data management system offers the users the possibility to import and to export data regarding specific training sessions and specific trainees. After logging into the application, the user can choose which feature to use further. The login screen design is shown in Figure 4 below.

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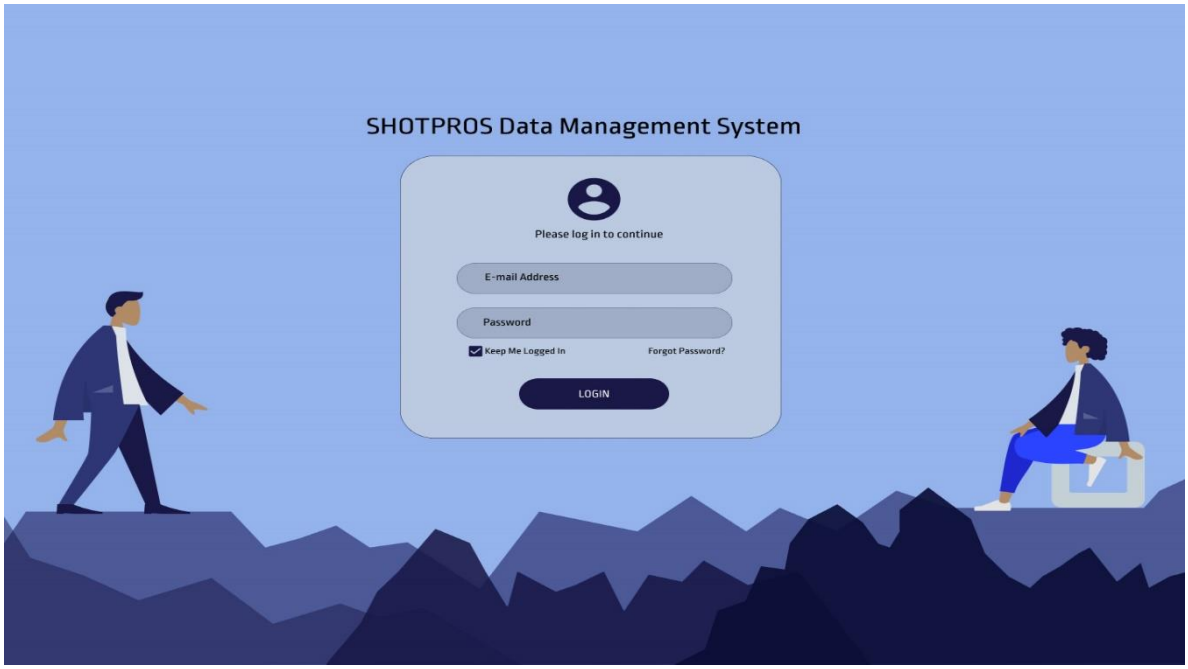

Figure 4: Login screen for the SHOTPROS data management web application.

When the user clicks on the Studies tab, an overview of the training studies conducted is shown. For each study, the unique study ID, the study name, description and overall study time are shown. Additionally, the user can expand the studies and see all the training sessions which were conducted during that particular study. This can be seen on the studies page shown in the figure below (see Figure 5).

Figure 5: Training studies overview

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The importing of the data is done by clicking on the tab for the import page. On this page, the user can view the training sessions. Based on the desired training session, the user can view the trainees which were part of the session. The user can import data for the training session as well by using the 'import' button for that session. When the import button is clicked, then a new window will be opened, where the user will have to add the desired file from its machine. After the file is added, the window will be closed. The user will receive a success message in the case when the import is successful or an error message in the case when the import was not successful. This screen can be seen on the figure below (see Figure 6).

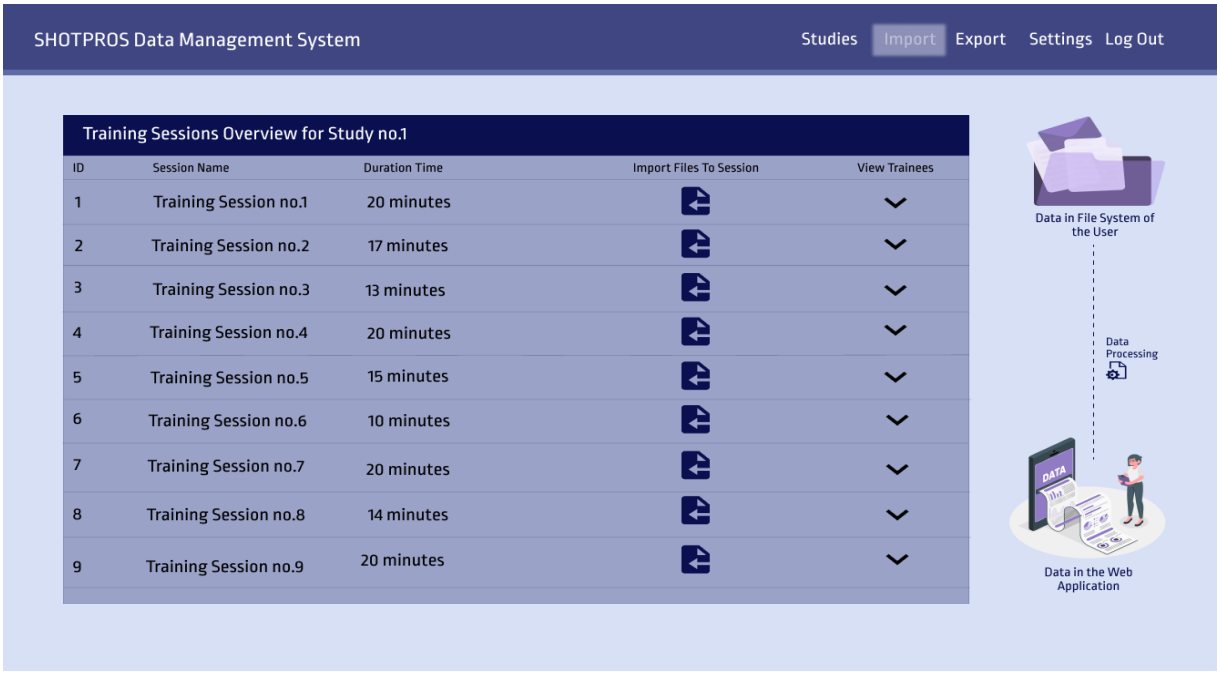

Figure 6: Import data screen of the web application

The feature for exporting the data has a similar flow. The flow starts by the user clicking on the tab for the export page. On this page, the user can iterate through the training sessions. Each training session field can be expanded, where the trainees who participated in that session can be viewed. For each trainee, there is an export button. The export of the data for the trainee is done by clicking on this button and after that a file or an archive of files (.zip) will be downloaded to the user's machine. Additionally, the user can export data for the whole training session. When the user exports data for the whole training session, the export is realised in a .zip file containing the following file structure: "TrainingSession/SessionNo./Trainees/Data1,Data2,Data3…". After the export button is clicked in both cases, the user is going to receive a success message the moment the file/files start downloading or an error message in the case where the export was not successful due to some error. The Export Screen can be seen on the Figure 7.

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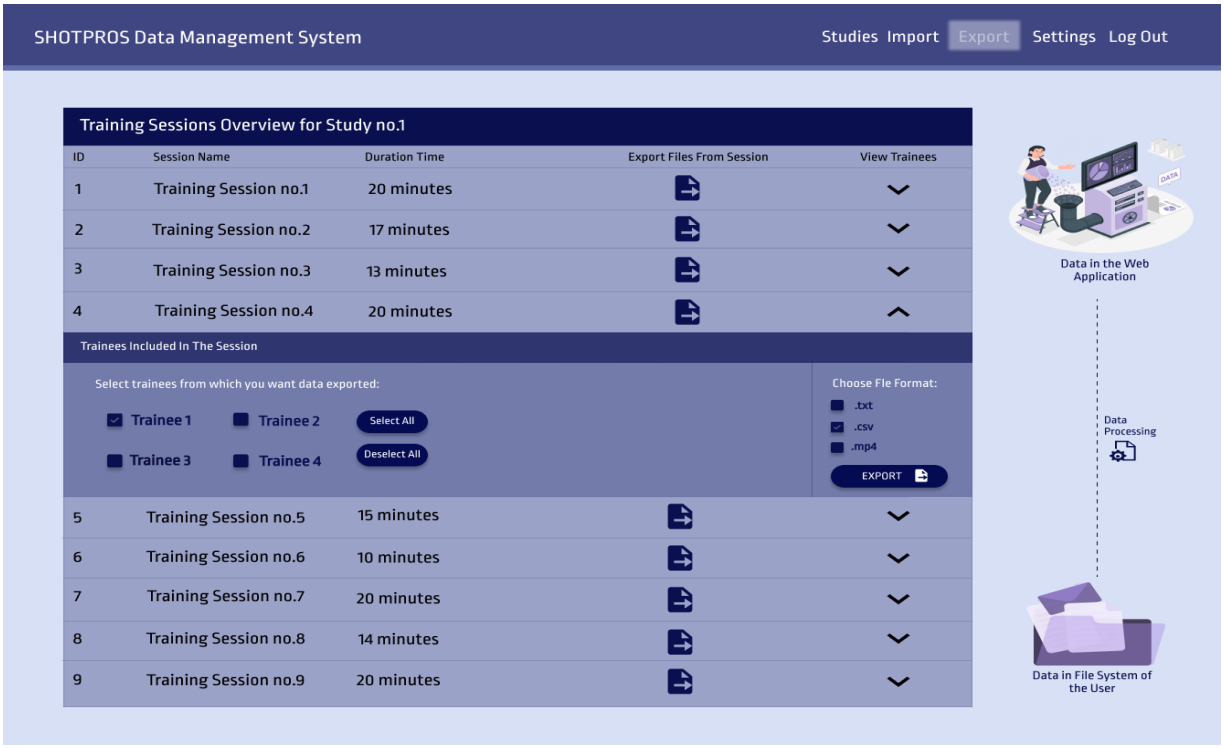

Figure 7: Export data screen of the web application

4.4 Data Analysis Methods and Tools

The following tools serve to support the evaluation of the data obtained from the HF studies. Depending on the subject area, different expert applications are used, or different tools are used to compare data (e.g. real time stress measurement) and to compare or evaluate the evaluation results.

Analysis of Physiological Data

- Zephyr OmniSense (https://www.zephyranywhere.com/system/omnisense-software)
  - Zephyr™ produce wearable technology that measure the physiological and biomechanical data for use contexts such as sports, combat, emergency situations and during research. Zephyr™ Performance Systems measure six key inputs that report on more than 20 biometrics. The OmniSense™ 5.1 cloud-based software enables end-to-end physiological and biomechanical load monitoring and analysis before, during, and after activities. It allows to capture raw data and turns it into insightful, easy-to-understand graphs and reports in real-time.
- Kubios (https://www.kubios.com/)
  - Kubios is a HRV analysis software for scientific research and professional use. It is compatible with several third-party heart rate monitors, electrocardiography (ECG)

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device and photoplethysmogram (PPG) monitors. It features built-in heart beat detection, automated pre-processing of data (e.g. noise handling, i.e. marking of selected data periods as noise to exclude them from HRV analysis), automatic heart beat correction, over 40 HRV analysis parameters, time-varying analysis, and detailed reporting.

- iMotions (https://imotions.com/)
  - iMotions is an integrated analysis platform made to execute human behavior research with high validity. The iMotions software integrates and synchronizes multiple biometric sensors that provide different human insight such as eye tracking, electrodermal activity (EDA)/galvanic skin response (GSR), electroencephalography (EEG), ECG and Facial Expression Analysis (FEA). iMotions funnels all the essential hardware technologies and their respective data into one consistent path for them to work seamlessly together. It can be used with diverse biosensors such as VR Headsets, eye trackers, or mobile EEG systems.
  - Only iMotions fulfilled the defined requirements due to the following characteristics:
    - iMotions provides a single software solution for controlling the experimental process, executing studies, and synchronizing multiple data streams. iMotions also has robust compatibility with external psychology stimulus presentation and analysis tools like MATLAB, SPSS, E-Prime, Psychtoolbox, and PsychoPy.
    - The software enables machine learning approaches, based on collected data from user behaviour. This feature could be interesting and will be tested and used within the D6.3

Statistical Analysis Tools

For the statistical analysis of questionnaire data and physiological data, a mixture of software tools such as Matlab, R and Excel will be utilised depending on availability.

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5 Resulting Human Factors Measurement Toolkit

The resulting HF measurement toolkit will comprise all necessary tools to collect, process, analyse and store results from the HF studies. This means that studies can not only be evaluated but also persistently stored for later analysis and comparison between training sessions and thus also training efficacy.

Based on the data, machine learning methods will be trained to develop better recognition and evaluation of behaviour (D6.4).

The toolkit is not limited to studies with VR and can therefore also be used for real trainings to evaluate human factors, stress assessment or training efficacy.

One example of the use of the toolkit for studies with the BLUESUIT system would be:

1. Study execution and data collection using questionnaires and the integrated sensors into the RE-liON System as well as possible additional sensors.
2. Transferring the data into the data management system using import filters and possibly adding meta data.
3. Execution of pre-processing and analysis steps with different tools. The data are provided by the data management system and results are delivered back into the database.
4. Visualization. In strong interplay to the Task Dashboard design, we will also define based on these data the visualization and will close questions such as:
    a. Which data (e.g. HRV, respiration) are important in real time to indicate stress?
    b. Which time stamps/sample rates are necessary in the measurements (see Shaffer & Ginsberg, 2017[2])?
    c. What is the difference in interaction design for the real-time and the after-action review?

The findings will then be transferred to BLUESUIT VR system. REL will implement the API and the algorithms within their system.

[2] Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in public health*, 5, 258. https://doi.org/10.3389/fpubh.2017.00258

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6 Data Privacy

D6.2 describes tools to collect qualitative and quantitative data within the HF measurement toolkit. In the following, we will thus shortly describe how the data collected through the HF studies will be managed and how data privacy will be handled.

Overall, the data management for the HF measurement toolkit follows the ethical guidelines and procedures defined in D1.2. The participants will give informed consent on any participation and will be briefed extensively (either orally or written) on the details of the study they will participate in (for details, see D1.2 as well as D9.2 for information on the informed consent procedure for participation and D9.6 for information on the informed consent procedure for data processing). Furthermore, all data from the HF studies will be pseudonymised, with each data subject receiving a unique identifier. For more details on the technical and organisational measures taken to ensure data privacy, please refer to D9.7.

7 Conclusions

The Human Factor Measurement Toolkit provides a convenient solution to centrally store and manage data from multiple studies with measurements and recordings conducted by different partners using different technologies and to make them available for more comprehensive analyses and for training of models using machine learning approaches based on the data and analysis results. Overall, we can highlight the following features and use cases presented in this deliverable: First, the HF measurement toolkit is easy to use by the partners to import and export required data or complete datasets. Partners have access to all data, and data are also easily shareable between partners. These data remain pseudonymised to protect trainees' data. Further, the toolkit integrates well into the existing tool landscape of the partners and integrates access control. The toolkit supports the various analysis processes and data formats well. Based on the data collected and analysed through the toolkit, a solid foundation exists to develop machine learning approaches as will be done in T6.3.

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8 Annex 1

The following data (items) can be recorded by the SHOTPROS VR system and will be used within the HF studies. The final selection of data entries is defined for each individual HF study. This list serves as a current overview (as of the end of April 2021) and will be updated through agile development or new requirements.

Data / Short Information (if necessary) – work in progress overview
Accuracy of engagement
Shot emplacement
Shots to kill target
Time between target detection to engagement
Split time between targets
Duration engagement
Shots missed in statistics tab and measure all missed impact (not hits on a target)
The user should be able to view shots danger close in statistics tab and event overview Measure the distance from a line of fire and team member Safe = 1 meter or more from the center of mass of the team member Mark as an event in the timeline and event overview
Target discrimination
Flagging team members
Movement: Define static positions for each door automatically
Range from Point of domination / team position
Range from ideal movement line
Able to view the average moving speed per person in the statistics tab (time in static positions not counted)
Time in static positions

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Time in red zones / killbox Able to view the time in seconds a person/trainee standing inside a killbox or redzone in the statistics tab
Crossing gun line Able to view number of events of crossing gun line of team members
Communication Mark communication events in the event overview
An instructor should be able to identify the correctness of actual movement according to spoken words of movement
Number of words Identify commands from bullshit words Able to show the efficiency percentage in the stats tab per person/trainee
Comms after (key) event Measure time between key event and communication Key events: - Team mate down ('Man down') - Hostage in FOV - Hostage secured ('Jackpot') - team enter building ('entry entry') - target/hostage not present in object ('dry hole') - target in direct vicinity of team member while moving, team member has to stop moving in order for the other team member to take a shot ('shot') - target is down after the term 'shot' , team members can move again ('shot clear') - door did not open after explosive breach ('failed breach') - team encounters suicide bomber and they want to leave the building as fast as possible ('landslide') - door does not open and needs to be breached with shotgun ('shotgun') - team member with shotgun reacts to request for shotgun ('ik heb shotgun') - door does not open after shotgun breach ('failed shotgun') - team member places explosive charge on door ('lading') - team needs to get off the hallway for explosive breach to take place ('clear the hall') - team member gives all clear sign for setting off explosive charge ('veiling') - team member setting of explosive charge ('standby') - team member want to go to alternative breaching point after failed breach ('alternatief')

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- team member wants to warn other team members for throwing a flashbang ('Eigen stun') - team has cleared last room in building ('last room') - sector has been cleared ('sector stabile') - object secured ('object stabile') - building needs to be prepared for stronghold - stronghold is ready ('Alamo') - start collecting evidence with time indication ('sweep + time') - collection of evidence ready ('stone') - fall back to to strongroom in the stronghold ('tornado') - time indication for team leaving the building ('homerun + time') - team has to get ready for leaving the building ('greed makes poor homerun') - team has to leave the building ('homerun nu') - teams ready for action but are put on hold ('red on') - teams can start their actions ('green on') - teams in positions for setting of explosive breach ('in positie') - sniper wants team to stop moving ('freeze')
An instructor should be able to identify the correctness of moment and means of communication
Measure average distance (spread) between impacts on a person per student/trainee 'Group size' of impacts
Measure impacts zone on a person per student/trainee
Impact accuracy calculated by 3 zones around the vital organs. 3 Spheres around the vital organs A B C TODO define vital organs
Measure time between first and last shot on a person per student/trainee Should be visible per NPC in the engagement statistics tab
Measure the time between target detection in FOV of trainee and engagement Engagement is: - First shot on target (could be a miss) - First verbal communication with target

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Measure the time between last finished engagement (killed target or finished communication to target) and engagement on next NPC; Targets should be in the same room Between start position and point of domination in a room (see req ID TODO) Should be visible per NPC in the engagement statistics tab
The user should be able to view amount of impacts on own team in statistics tab
The user should be able to view amount of impacts on civilians in statistics tab
Measure the distance from the ideal movement line per student/trainee
Automatically define the ideal movement lines Calculated from the static positions at the doors to the point of domination. Use pathfinding to determine the shortest path. Make sure killbox is not used
Should be able to define the point of domination during scenario edit
Able to view the percentage relative of the ideal movement per person in the statistics tab
Able to view the percentage relative from the point of domination per person in the statistics tab
Measure the time between static positions (still in movement)
Measure time when standing still
Engagement statistics tab; The tab views NPCs in 3D without background in sort of T-Pose (pose between Npose & Tpose)
The user should be able to view the split time between NPCs in the tab when 2 or more NPCs are added to the engagement tab
The engagement tab should be cleared when shortcut to another event is clicked from the event overview
The user should be able to view identification duration per NPC
The user should be able to view engagement duration per NPC
The user should be able to filter engagement events per person (impact etc)

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The user should be able to view amount of hits per NPC per zone
The user should be able to view an event in the timeline and event overview when impacts hit on own team
The user should be able to view an event in the timeline and event overview when impacts hit on civilians
The user should be able to view an event in the timeline and event overview when a team member crosses the line of fire
Event overview Show all events in the top view map on the spectator of an AAR
time stamps regarding the beginning and the end of a “tuned on” stressor. (no matter if activated by the trainer or fixed within the scenario). As soon as you select another stressor, or a stressor starts (due to the storyboard – a non-selectable stressor) the beginning time and the end time of this stressor is stored and will be available as a data set for the evaluation afterwards (export with the other data)
Which stressors were used (selected and pre-selected or fix part of the scenario)
List of used stressors with time step

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9 Annex 2

9.1 Appendix A: Questions for Quantitative Assessment

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Questionnaire	Item Code	Label	Question	Response	Response Code
Training Information	Q1.1	Group	To which training group do you belong?	1	A
				2	B
				3	C
	Q1.2_1	Particip ant	Participant number		
	Q1.3	Training	Which training did you do?	1	VirTra Shooting Simulator
				2	VR Training
Quality of Learning	Q2.2	qol_1	How sure are you that you can put what you learned in this training into practice?	1	Not at all sure
				2	Only partially sure
				3	Neutral
				4	Sure
				5	Very safe
	Q2.3	qol_2	If any of the situations trained with this system occur in practice, I will be able to master them better.	1	Doesn't apply at all
				2	Doesn't apply
				3	Neutral
				4	Applies
				5	Applies completely
	Q2.4	qol_3	Thanks to the training, I will be able to deal with demanding operational situations more safely in the future.	1	Doesn't apply at all
				2	Doesn't apply
				3	Neutral
				4	Applies
				5	Applies completely
	Q2.5	qol_4	After their experience with the VR training system, how do they assess the usefulness of complementary VR training in police training?	1	Not at all meaningful
				2	Not meaningful
				3	Neutral
				4	Meaningful
				5	Extremely meaningful
VAS	Q3.1_1	vas_str	0-100		Visual Analogue Scale - Stress Thermometer
	Q3.2_1	vas_rsm	0-150		Visual Analogue Scale - Rating Scale for Mental Effort

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Quality of Experience	Q5.2_1	adiff_p1	Simple - Complicated	1= left 7= right	Items: 10 semantic differential pairs Scale: 7-point radio button scale between the semantic differential pairs
	Q5.2_2	adiff_a1	Ugly - Attractive		
	Q5.2_3	adiff_p2	Practical - Impractical		
	Q5.2_4	adiff_h1	Stylish - Tacky		
	Q5.2_5	adiff_p3	Predictable - Unpredictable		
	Q5.2_6	adiff_h2	Cheap - Premium		
	Q5.2_7	adiff_h3	Unimaginative - Creative		
	Q5.2_8	adiff_a2	Good - Bad		
	Q5.2_9	adiff_p4	Confusing - Clearly structured		
	Q5.2_10	adiff_h4	Dull - Captivating		
	Q5.4	vrqoe_1	How would you rate the overall quality of your experience with the system?	1	Bad
				2	Poor
				3	Fair
				4	Good
				5	Excellent
	Q5.5	vrqoe_2	How would you rate the visual quality of your experience with the system?	1	Bad
				2	Poor
				3	Fair
				4	Good
				5	Excellent
	Q5.6	vrqoe_3	How would you rate the audio quality of your experience with the system?	1	Bad
				2	Poor
				3	Fair
				4	Good
				5	Excellent
	Q5.7	vrqoe_4	How would you rate the quality of the interaction (responsiveness, controllability, freedom to move and act) with the system?	1	Bad
				2	Poor
				3	Fair
				4	Good
				5	Excellent
	Q5.9	eud_1	Training with the system makes me feel fulfilled.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q5.10	eud_2	Training with the system provides me with a sense of purpose.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree

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				4	Agree
				5	Strongly agree
	Q5.11	eud_3	Training with the system will make me a better police officer.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q5.12	eud_4	Training with such a system will help me in developing my personal potential.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
Technology Acceptance Questionnaire (for Police VR use)	Q6.2_1	tac_eas_1	I think the virtual environment is easy to use	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.2_2	tac_eas_2	I think the virtual environment is comfortable to use	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.2_3	tac_eas_3	It was easy for me to learn how to use the virtual environment	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.2_4	tac_use_1	The virtual environment allows me good training performances	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.2_5	tac_use_2	The virtual environment helps me to better understand the training content	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.2_6	tac_use_3	The virtual environment helps me gain knowledge about training content	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree

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				4	Agree
				5	Strongly agree
	Q6.3_1	tac_use_4	I think the virtual environment is a good training tool	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.3_2	tac_intern_1	I think the virtual environment supports me in my training progress	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.3_3	tac_intern_2	I would be ready to use the virtual environment in my future workouts	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.3_4	tac_intern_3	I would be willing to share my knowledge of the virtual environment with other trainees	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.3_5	tac_intern_4	I would like other trainees to use the virtual environment for training	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.3_6	tac_img_1	I think the virtual environment helps me assess my position relative to my teammates	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.4_1	tac_img_2	I think the virtual environment helps me to experience my own danger realistically	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.4_2	tac_img_3	I think the virtual environment helps me	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree

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			better understand critical processes	4	Agree
				5	Strongly agree
	Q6.4_3	tac_img_4	Training in the virtual environment is more interesting than without a virtual environment	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.4_4	tac_imm_1	Training in the virtual environment is fun	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.4_5	tac_imm_2	I like to use the virtual environment for training	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.4_6	tac_imm_3	I inform myself about electronic devices, even if I have no intention of buying.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_1	tac_interr_1	I love owning new electronic devices.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_2	tac_interr_2	I'm thrilled when a new electronic device comes on the market.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_3	tac_interr_3	I like to go to the specialist trade for electronic devices.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_4	tac_interr_4	I enjoy trying out an electronic device	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree

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				4	Agree
				5	Strongly agree
	Q6.5_5	tac_enj _1	Training in the virtual environment is more interesting than without a virtual environment	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_6	tac_enj _2	Training in the virtual environment is fun	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.5_7	tac_enj _3	I like to use the virtual environment for training	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.6_1	tac_cur _1	I inform myself about electronic devices, even if I have no intention of buying.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.6_2	tac_cur _2	I love owning new electronic devices.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.6_3	tac_cur _3	I'm thrilled when a new electronic device comes on the market.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.6_4	tac_cur _4	I like to go to the specialist trade for electronic devices.	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree
				4	Agree
				5	Strongly agree
	Q6.6_5	tac_cur _5	I enjoy trying out an electronic device	1	Strongly Disagree
				2	Disagree
				3	Neither agree, nor disagree

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				4	Agree
				5	Strongly agree
SOPI[3]					
User Background	Q4.3_1	BG1	How do you rate your level of computer experience?	1	New
				2	Beginner
				3	Advanced
				4	Expert
	Q4.3_2	BG2	How do you rate your level of knowledge about how 3D images are produced?	1	New
				2	Beginner
				3	Advanced
				4	Expert
	Q4.3_3	BG3	How do you rate your level of knowledge about virtual reality (for example how it works)?	1	New
				2	Beginner
				3	Advanced
				4	Expert
	Q4.4	BG4	How often do you play computer games?	1	Never
				2	Occasionally (once or twice a month)
				3	Often, but less than half the days
				4	Half or more of the days
				5	Every day
	Q4.5	BG5	Have you experienced virtual reality before? (multiple answers possible)	1	No
				2	Yes, with a consumer system
				3	Yes, with a professional system in an arcade
				4	Yes, in a training environment
				5	Yes, in a research setting
				6	Yes, otherwise
	Q4.6	BG6		TEXT	If 6, specify
Spacial Presence	SPA01 – SPA19			1-5	Strongly Disagree – Strongly agree
Engagement	ENG01 – ENG13			1-5	Strongly Disagree – Strongly agree
Ecological Validity/ Naturalness	ECV01 – ECV05			1-5	Strongly Disagree – Strongly agree
Negative Effects	NEF01 – NEF06			1-5	Strongly Disagree – Strongly agree

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Additional Item	SOPIB6		1-5	Strongly Disagree – Strongly agree
AIT Extra Items	SOPIX1	How would you rate the overall quality of your experience with the system?	1	Bad
			2	Poor
			3	Fair
			4	Good
			5	Excellent
	SOPIX2	Did you experience problems?	1	Yes
			2	No
	SOPIX3	If yes, which ones?	Text	

9.2 Appendix B: Guidelines for Qualitative Interviews

9.2.1 Questions to both trainees and trainers

1) What was positive, what worked well?
2) What was negative, what did not work well?
3) Which ideas/proposals do you have for improving the training?

9.2.2 Questions to trainers only

1) Which training objectives can be trained well with the system from your point of view?
   a) Tactical training: *tactical procedures such as entering a spacing, scanning a room, car procedures*
   b) Personal safety ("Eigensicherung"): *distance to suspect, protection within a team (e.g. 360 degree protection)*
   c) Shooting and weapon handling training: *correct handling and precise shooting of the various service weapons*?
   d) Fitness training: *physical components such as endurance and strength*
   e) Combat training: *various close combat skills for self-protection and to handcuff suspects (also includes training with the baton)*
   f) Law and regulations training: *theoretical lessons and scenario training in which laws and regulations need to be considered*
   g) Communication training: *de-escalation tactics, contact communication, regular interactions with civilians*

[3] Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J.D. (2001). A Cross-Media Presence Questionnaire: The ITC Sense of Presence Inventory. Presence: Teleoperators and Virtual Environments, 10(3), pp 282-297.

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h) Perception and action ("Wahrnehmung und Verhalten") *perceiving suspicious behaviour/threats instantly and reacting/behaving fast and correctly (training of quick reaction time with minimal error in perception, also decision-making training)*

i) Situation training: *exposure to various scenarios to combine skills and competencies a nd familiarize officers with different levels of stress*

j) Psychological competency training: *enhancing mental capabilities and techniques to r educe stress (e.g. breathing techniques), exerting situational control, etc.*

2) How should training progress be measured best in the VR system from your point of view?

3) What is your overall opinion about integrating gamification elements into training? (e.g. symbolic rewards, medals, achievements points, pain stimuli)

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