Abstract: Police communication is a field with unique challenges and specific requirements. Police officers depend on effective communication, particularly in high-stress operations, but current training methods are not focused on communication and provide only limited evaluation methods. This work explores the potential of virtual reality (VR) for enhancing police communication training. The rise of VR training, especially in specific application areas like policing, provides benefits. We conducted a field study during police training to assess VR approaches for training communication. The results show that VR is suitable for communication training if factors such as realism, reflection, and repetition are given in the VR system. Trainer feedback shows that assistive systems for evaluation and visualization of communication are highly needed. We present ideas and approaches for evaluation in communication training and concepts for visualization and exploration of the data. This research contributes to improving VR police training and has implications for communication training in VR in challenging contexts.

Keywords: virtual reality; communication; training; police

1. Introduction

In their daily work, police officers are often confronted with complex situations. Especially in critical situations (e.g., usage of a shooting weapon from suspects, involvement of vulnerable groups such as children, etc.), factors such as stress and time pressure can pose great challenges to police officers [1]. Therefore, adequate communication skills are an essential resource for police officers [2] and can significantly reduce the risk for police officers during their missions [3]. Inadequate or misused communication carries the risk of triggering serious conflicts [3]. Police response teams are often the first on the scene [1] and are confronted with complex and potentially dangerous situations that have a high potential for conflict [2,4]. The ability to communicate in a targeted manner can have a far-reaching influence on the quality and outcome of operations [3].

However, communication training is not simple. Communication is a complex process influenced by various factors [5], including external influences [6], misunderstandings [7], and differing levels of knowledge [6].

Communication during such operations is divided into two main categories: (1) inward-facing communication, and (2) outward-facing communication [2], and depends strongly on the communicative counterpart. Outward-facing communication refers to communication with non-first responders, such as people in civil society [2]. Inward communication is communication within participating first responders. This can include the police, fire brigade, rescue services, emergency medical personnel, crisis managers, and other organizations [8].

This work addresses communication training for police forces in operational high-stress training, focusing on inward-facing communication. We distinguish between commu-
communication within a police team and between the team and the police control center. A police control center is a central operational hub that plays a critical role in the effective functioning of law enforcement agencies. It serves as a command and coordination center, coordinating and managing various aspects of police operations, emergency response, and public safety efforts. It is relevant that the context pertains to training for high-risk and high-stress situations (such as scenarios with weapons) as opposed to low-risk or low-stress police tasks (such as questioning witnesses at a traffic accident).

We investigate how virtual reality (VR) technology can enable or enhance communication training. From the literature in communication sciences, we identified realism, repetition, and reflection as the main factors enabling effective communication training (see Section 2.3). As repetition is an inherent feature of digital simulation-based training systems such as VR technology, our research questions focus on whether VR provides adequate realism and reflection for police communication training, as well as how future interfaces should be designed in this context. The central research questions are, therefore, as follows:

- **RQ1:** How effective is VR technology in enhancing communication training for police officers in high-stress operational scenarios?
  - **RQ1-A:** Can VR technology adequately provide realism in the context of communication training for police officers in high-stress operational scenarios?
  - **RQ1-B:** To what extent does VR technology facilitate effective reflection for police officers during communication training in high-stress operational scenarios?
- **RQ2:** What design ideas or implications are relevant for future developments?

The contributions of this paper are as follows:

- We provide insights from a user study ($n = 63$ police officers and $n = 8$ police trainers) and expert workshop ($n = 8$) regarding using virtual environments for communication training.
- We discuss approaches and ideas for future VR systems for police communication training for high-stress operations.

The remainder of the paper is structured as follows: In Section 2, we briefly review the topics of training in VR, define the context of scenario-based police training in VR, and discuss the relevant factors for VR training. We also provide an overview of the topic of police communication training. Section 3 presents our field study design and results, and Section 4 describes the methodology of an expert workshop and the corresponding results. Following this, in Section 5, we discuss the results concerning RQ1 (A and B) and RQ2, present limitations, explore avenues for future research, and offer our conclusions.

2. Related Work

In the context of police tactical training, a frequent training method is scenario-based training. In scenario-based training, trainees are presented with carefully crafted scenarios by experienced trainers and are required to collaboratively resolve these scenarios as a team.

This related work section gives an overview of the current state of the art in VR training with a focus on the context of police training. Furthermore, attention is given to the topic of communication within the police force and an exploration of the current methods employed for training in this area.

2.1. Training in VR

Virtual and augmented technologies for training are becoming increasingly popular and are used in various domains [9,10]. Since this work deals with using VR as a training tool for the police, the focus here is on the training sector.

This trend towards VR as a training tool can be observed within the domain of training for first responders generally, including law enforcement [11,12], fire departments [13], medical experts [14], and first responders to chemical, biological, radiological, and nuclear (CBRN) incidents [15,16]. It is particularly valued as an effective tool for training in
professions where mistakes in real-life situations can pose a grave threat to individuals and potentially result in loss of life [15,17,18].

Related work suggests that using VR is beneficial, especially in training domains characterized by complexity and being difficult to master [19,20]. VR offers secure, effective, and resource-efficient training, particularly tailored to the needs of these specific groups as they prepare for demanding scenarios [21,22]. Furthermore, virtual worlds enable collaborative learning and support factors such as fun but also support communication [23].

2.2. Police Scenario Training in VR

To ensure effective training, extensive exercises are needed [15] as conventional operational training often requires enormous organizational effort. Especially, large-scale exercises are difficult to orchestrate [15], are a logistical challenge [24], and sometimes pose safety challenges for the organizers. In addition, the organization of such operational training is also very costly in terms of time and money [15,24,25].

Apart from the organizational difficulties, this type of training cannot fully reflect the complexity of real operations [26]. Such training scenarios do not realistically represent the often very dynamic and complex deployment and conflict situations [5,27]. However, realistic training is fundamental to preparing police officers for high-stress situations because it is the only way to ensure that the skills learned can also be called upon in real operations [28]. Furthermore, current training is minimal in terms of feedback and reflection options [11]. However, feedback is elementary for reflection in the course of deployment training [29].

The use of VR could be the answer to some of these problems. In the police context, operational training with the help of VR has gained importance [30]. VR training has a comparatively low organizational effort compared to existing training simulations [24] and its easy accessibility and availability is a particular advantage [31]. In addition, the improvements in affordability of VR are a positive factor [10]. Although the initial costs of the equipment are high, the content of the scenarios and the local relocation can be orchestrated very cost-effectively [11].

2.3. Relevant Factors for VR Training

Giessing and Frenkel [24] emphasize diverse manipulability as a strength of virtual reality. Operational trainers can intervene in factors such as sequence, complexity, and the risk presented. These various controllable factors can be used to address individual needs and goals [24]. Furthermore, one factor that can be controlled to a certain extent with the help of virtual reality is stress [30], through the manual manipulation of various stress factors (e.g., the presence of weapons, shouting, or even injured people). The manipulability of VR allows trainers to control the training situation, and the participants can be offered an individualized training opportunity.

Controlling the scenarios in VR also creates a learning environment that makes it easy to include repetition in the training practice [32]. Scenarios can be adapted, changed, and trained again without much effort [15]. By keeping the scenarios consistent, police officers can stabilize their skills. By adjusting during this repetition, the flexible adaptation of the learned skills to changing circumstances can additionally be trained [24].

2.3.1. Realism

According to the literature, realistic training scenarios are needed to ensure adequate preparation for real police operations [5,11,28]. This includes the highly complex and stressful nature of police operations [5,28], as well as the inclusion of realistic and ideally inter-agency teams, as they occur in real operations [1]. This ensures that the skills learned can be successfully recalled in real operations [29].

The realistic presentation, high level of control over training scenarios, and the possibility to interact with the environment as well as avatars are distinguishing features and significant advantages of VR [24,33,34].
To enhance realism, it is crucial to address the various dimensions of realism that go beyond graphical fidelity only. Beyond the visual quality, the incorporation of interactive actors, non-playing characters (NPCs), and physical props, such as tangible objects and gear, significantly enriches the training environment [35,36]. These elements introduce a layer of interaction that mirrors real-world conditions more closely, allowing trainees to engage with dynamic and responsive elements within the simulated scenarios. This not only enhances the realism of the training exercises but also allows a more comprehensive evaluation of a police officer’s ability to perform complex interactions under stress. Thus, this increases the overall effectiveness of the training program.

In particular, communication in highly complex and dangerous situations, which emergency forces are often confronted with, can be trained realistically. These scenarios are usually tricky to simulate in conventional training realistically [24,30,37].

2.3.2. Repetition

Repetition can help police officers prepare adequately for complex situations [24]. Communication skills include gaining confidence in one’s abilities, memory training, improving intuitive decision-making under stress, and correcting incorrect behavior patterns [29,31]. VR also supports this. The high control over scenarios enables a straightforward repetition of scenarios [24,32]. In the process, individual factors can be adapted to the needs of the learners to improve the learning experience further [15].

Moreover, the immersive nature of VR allows for a comprehensive sensory experience, which is crucial for simulating real-world conditions. This sensory immersion helps in ingraining the learned behaviors more deeply into the police officers’ responses, providing a more instinctual reaction during actual high-pressure situations [38]. The capability of VR to simulate complex interpersonal interactions also offers police officers the opportunity to practice and evaluate communication strategies in a variety of challenging scenarios. This repeated exposure to high-stress conditions without real-world consequences not only enhances their skills but also aids in reducing the psychological stress associated with real-life encounters [39].

2.3.3. Reflection

Reflection, feedback, and debriefing are essential, especially for identifying blind spots, such as errors in memory and perception. According to the literature, feedback and debriefing are particularly helpful if not only verbal but also visually supported [7,29,40]. VR can be beneficial here. The exact training simulations can be recorded and used in after-action review (AAR) [41] and debriefing as visual support. This way, errors, possible cognitive distortions, and blind spots can be reflected [7,15,24]. The ability to visually review VR training sessions provides immediate, actionable feedback and allows for a more detailed analysis of the police officers’ behavior and decision-making processes. By replaying the scenarios, trainers and trainees can pause at critical moments to discuss alternatives and better approaches to handling similar situations in the future.

This detailed, replay-enabled debriefing and after-action review aids in the development of critical thinking and adaptive strategies, further enriching the training experience [12]. Moreover, after-action review as a reflective practice supported by VR technology can significantly improve long-term memory retention and behavioral change, making it a highly suitable tool [10,27] in the field of law enforcement training.

2.4. Communication Training within the Police

Communication is a key competence for police officers, without which they cannot effectively perform many of their duties [2,3,26,42,43]. Therefore, communication significantly influences the outcome of police operations [2,3]. Consequently, appropriate communication skills are an essential requirement for the collaboration and success of first responder teams, such as police [6,44,45].
Furthermore, communication has a substantial impact on the behavior of third parties. Among others, communication is a crucial factor in conflict prevention and de-escalation [3,26,46–48]. Especially in high-risk situations with significant conflict potential, communication skills can significantly reduce the risk for police officers [3,48]. However, communication is a complex process with many influencing factors [7], which is particularly essential in critical situations [3]. Especially under stress, the retrieval of competencies can be very challenging. Therefore, appropriate training is vital to prepare police officers for these situations [26].

According to Staller et al. [7], various blind spots must be overcome to ensure professional police communication. Among other things, the underestimation of one’s blind spots is mentioned, and the importance of reflection is pointed out. To establish this and to learn communicative competencies appropriately, conscious training of these skills is needed [43,49]. However, problems can also be identified in this regard.

Currently, there is not much focus on teaching and reflecting on communication in the training of police officers [7,50]. Furthermore, there is a lack of suitable criteria to adequately assess this communication [50]. Current training also lacks realism [5], while realistic training scenarios are an important factor for adequate communication training [5,11,28].

It is crucial to emphasize that the effectiveness of VR as a training tool is not merely a function of the technology itself but is highly contingent upon the instructional design implemented [51]. Each design choice impacts the learning outcomes by either enhancing or limiting the engagement and cognitive absorption of the trainee. Effective instructional design in VR must, therefore, be carefully planned to incorporate elements such as interactivity, realistic scenarios, immediate feedback, and adaptive learning paths that match the individual learning styles and needs of users. This approach ensures that the potential of VR to simulate complex, real-world environments translates into actual learning and skill development. By integrating proven instructional strategies, VR training programs can be optimized to provide more comprehensive learning experiences [52].

Two methods were chosen to close the research gap and answer the research questions. First, a field study was conducted during VR police training involving trainees and trainers. Second, an expert workshop was carried out with high-level experts in the field of police training.

3. Field Study

The field study was conducted during a real operational training session conducted by a European [hidden for review] police authority in spring 2023. Over one week (five days), we conducted our study on the topic of ‘Usage of VR for Police Communication Training’. The study aimed to assess the potential future use of VR in communication training for police officers, specifically focusing on its suitability for operational training in high-stress scenarios (RQ1) and the generation of ideas and approaches for future systems (RQ2).

Our study concentrates on two primary communication paths: communication within police teams (comprising three or four individuals) and communication between these teams and the police control center. It is important to note that the study’s setting involved training for high-stress operations, and the scenarios were determined by law enforcement authorities rather than our research team. Additionally, it is crucial to consider that this training was a genuine police training exercise. Consequently, when designing the study, we also considered the time constraints of the police officers to avoid disrupting their training schedule.

3.1. Method

To address our research questions, we conducted a field study accompanying a running VR police training program involving 63 police officers as trainees and 8 trainers. During the study, we collected data through a questionnaire incorporating quantitative and qualitative questions. Following the field study, we organized an expert workshop
with eight participants to synthesize and analyze the collected findings for deeper insights into the effectiveness of VR as a tool for enhancing police team communication. This workshop included representatives from the police administration (Ministry of the Interior), experienced police trainers, and experts from law enforcement agencies with expertise in technical matters, including VR training.

Regarding ethical and data protection aspects, the study design was planned and implemented in collaboration with experts and representatives of the police authorities. Specifically, since the field study was conducted during real training sessions and within service hours, the design was reviewed and approved by internal bodies.

3.1.1. Technical Setup

Police officers trained in a VR arena (Figure 1a) that features optical tracking and provides a 10 m × 10 m space for unrestricted movement. Each participant wore a backpack computer linked to a head-mounted display (HMD), along with markers on their hands and feet to facilitate full-body avatar animation. Trainees were also provided a physical mock rifle, seamlessly integrated into the VR experience (Figure 1b). The training scenarios were conducted using the Refense training system (available at https://www.refense.com/; accessed: 14 September 2023). The trainees were equipped with a headset and a microphone to communicate with each other and the control center. The control center was simulated by an experienced operator who reacted to the incoming radio messages or gave information appropriate to the scenario.

![Figure 1. (a) Picture from the VR training arena and the optical tracking setup. (b) Picture of three (one training team) police officers wearing a backpack PC and an HMD during the VR scenario training.](image)

3.1.2. Participants

Two participant groups were involved in the field study: police trainees and police trainers. The trainees were assigned and organized for the training by the police authority. In advance, teams consisting of three or four individuals were assembled to arrive at a designated time in the training facility. A total of 63 police officers (53 male and 10 female) with a mean age of M = 36.9 years (SD = 7.9) participated in the study, split up into 18 teams (3 or 4 persons per team). The police officers had a mean experience on the job of M = 9.4 years (SD = 7.6), and for most (50/63) it was their first VR experience. Some (10/63) had experienced VR once, and a few were more frequent users (3/63). Additionally, eight police trainers participated in the study (2 female) during the week, to gather feedback from the didactical and organizational side. The trainers had a mean age of M = 38.1 years (SD = 6–9) and had a mean experience as a trainer of M = 8.4 years (SD = 3.3).

3.1.3. Procedure

The training was conducted in a VR center. The hall was made available during the day for the police to conduct the training. Police officers arrived at the training facility in teams of three to four people, directly from their duty shifts and in uniform. Upon arrival, they were required to securely store their service weapons in a designated safebox (lockable gun cabinet). The participants were then briefed, first by the professional trainer about
the day’s training outline, and subsequently, by the research team regarding the study’s objectives and expectations.

After the briefings, all officers signed informed consent forms to participate in the research. Subsequently, trainees were equipped with specialized VR gear, which included foot and hand trackers, a prop gun designed for the simulation, and a backpack PC.

Following an initial tutorial session to familiarize themselves with the VR setup, the trainees participated in two distinct training scenarios. After each scenario, they engaged in an after-action review (AAR) led by the trainer (Figure 2b) and filled out a questionnaire designed to capture immediate feedback on their experience and performance in the scenario. AAR is a standard debrief procedure in the military and other fields that rely on performance reviews to enhance learning [53].

During the AAR, the training instructors provided individual and team feedback and collaboratively developed optimized courses of action. As a visual aid, a virtual recording of the recently experienced scenario was utilized. Upon completion of both training scenarios and post-training activities, participants filled out a final questionnaire evaluating their overall experience before being thanked for their invaluable contribution to the study.

![Figure 2. (a) Screenshot of the second scenario from a bird’s eye view. The icons show pre-defined non-playing characters (NPCs) or the status of controllable elements such as door open or closed. (b) Photograph of the AAR with a police training team and their trainer (red). The trainer shows individual sequences of the training and gives feedback to the participants.](image)

3.1.4. Training Scenarios

For the training, two scenarios were created by the police authority, lasting approximately ten minutes each. The training focus was on the following three factors: (1) De-escalation and communication training, (2) appropriate search behavior before contact with perpetrators (this includes swarming, searching rooms, and team communication), and (3) behavior as soon as a shot is fired (this includes, but is not limited to, team huddling, clear team communication and hierarchy, and tactics employed). The following are brief descriptions of the two scenarios. Further details about the scenarios or specific tasks of the police officers cannot be published in this work to prevent the derivation of tactical procedures or the development of counter-tactics.

In the first scenario, the police officers were informed by the control center about multiple gunshots and an unknown number of perpetrators in an office building. During the scenario, the police officers encountered various civilians (referred to as “Oscar”) and two armed perpetrators (referred to as “Tango”) distributed across two floors of the building. Tango 1, armed with a firearm, responded cooperatively after appropriate communication, while Tango 2 immediately initiated an attack with a knife.

In the second scenario (Figure 2a), the police officers were informed by the control center about multiple gunshots and an unknown number of perpetrators in an office building. It is important to note that the layout of the rooms differed from the first scenario. During this scenario, the police officers encountered various civilians (“Oscars”) and two
armed perpetrators ("Tangos") distributed across two floors of the building. In this scenario, Tango 1 fired continuous shots. After contact, this time the instructions of the police officers were not followed. Once Tango 1 was neutralized, the control center informed the team about additional victims and potential perpetrators on the second floor. The behavior of Tango 2 in this scenario depended on the actions of the police officers. If Tango 2 was recognized and addressed appropriately, they acted cooperatively. If not recognized, Tango 2 fired shots.

3.1.5. Measurements

To address RQ1, we evaluated the three key factors identified in our state-of-the-art analysis as essential for effective VR communication training in the police context: realism, repetition, and reflection. Given that repetition is an inherent feature of VR training systems, our study aimed to determine whether the VR system provided an adequate level of realism and supported reflection.

Realism and Training Experience

To effectively train team communication, the training must be as realistic as possible; otherwise, essential communication between team members, the command center, and bystanders may not occur. For example, a highly realistic training environment might lead to observations that are communicated that would not be communicated in a less realistic environment. Thus, to evaluate whether the VR training program provides sufficient realism for communication training, we developed and administered a questionnaire targeting several aspects of user experience, including realism, ease of use, quality of learning, quality of interactions, and imagination. The questionnaire consisted of 16 items, rated on a 5-point Likert scale ranging from “strongly disagree” to “strongly agree”. The construct of realism was assessed through four items, such as “The virtual environment creates a realistic training scenario” and “Virtual agents in VR behave realistically”. Ease of use was evaluated with two items, including “The virtual training is easy to use” and “It was easy for me to learn how to use the virtual training”. Similarly, quality of interactions and quality of learning were each assessed through two items. Imagination was evaluated via two items, such as “The virtual environment helps me to realistically experience risks to myself and others”. Additionally, one item assessed participants’ intention to use the system in future training sessions.

As the field study was conducted within a research “in-the-wild” approach [54,55], we had to administer short questionnaires to fit into the tight training schedule of the police professionals. Thus, this questionnaire was designed for our study, drawing from existing scales on presence and technology acceptance and including uniquely crafted items to target our research objectives.

Reflection

In a series of preliminary interviews with the head of training of the police institution, relevant factors for a team’s communication performance were identified based on current training practices. We focused on internal communications, i.e., within and between the team and the control center.

Four factors were identified for team communication: (a) task distribution within the team, (b) precision of the team leaders’ instructions, (c) precise communication within the team, and (d) an overall evaluation of the communication performance. For communication with the control center, four factors were identified: (a) precision and conciseness, (b) timeliness, (c) precision of the final report, and (d) overall evaluation of communication with the control center.

To see whether the VR training, including the AAR, allows for adequate reflection, we let trainees and their trainers rate their communication performance on these four factors after each training block (after the AAR). The items are presented in Table 1: Constructed
items for communication performance (a) within the team and (b) with the control center. Items were rated on a 5-point Likert scale (Table 1).

**Table 1.** Constructed Items for communication performance (a) within the team and (b) with the control center. Items were rated on a 5-point Likert scale.

<table>
<thead>
<tr>
<th>(a) Team Communication</th>
<th>(b) Control Center Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>The task distribution was carried out precisely through targeted communication.</td>
<td>During the operation, essential information was communicated to the control center clearly and precisely.</td>
</tr>
<tr>
<td>The team leader gave precise and unambiguous instructions to colleagues.</td>
<td>During the operation, essential information was communicated to the control center promptly.</td>
</tr>
<tr>
<td>The team members communicated precisely during the operation and exchanged essential information.</td>
<td>After the completion of the operation, a clear and precise final report was relayed to the control center.</td>
</tr>
<tr>
<td>Generally, I rate the communication within the team positively.</td>
<td>Generally, I rate the communication with the control center positively.</td>
</tr>
</tbody>
</table>

Open Questions

To further gather qualitative insights on the suitability of VR for communication training, both the trainers (in their trainer-specific questionnaire; see next section) and the trainees at the end of the training answered the question: “In comparison to traditional operational training, to what extent do you think virtual reality supports communication training?”. Traditional operational training in the police field typically involves scenario-based drills and classroom instruction, where officers learn various procedures and tactics for handling different law enforcement situations. This training often includes role-playing, physical conditioning, use of force simulations, and legal education to prepare officers for real-world interactions and emergencies. However, these exercises frequently do not take place in real-life contexts, and role players are often fellow police team members, which limits the diversity of scenarios, such as interacting with children or elderly individuals. Additionally, training is usually recorded with cameras that provide basic visual records but lack advanced visualization or automatic analysis capabilities, such as measuring distances between individuals or tracking the frequency of tool usage.

Trainer Specific Questionnaire

In addition to the performance ratings of their teams after each scenario, the trainers further completed a one-time questionnaire on their experiences and opinions of communication and VR training. In it, they answered open questions regarding the importance of communication competencies in current operational training, existing communication guidelines and evaluation criteria, desired measurement of successful communication, improvements of the VR system for better communication, and opinions on standardized questionnaires for evaluation and reflection of operational training.

Furthermore, they rated VR’s suitability for different training objectives on a 5-point Likert scale (tactical training, self-protection, weapon handling, fitness, hand-to-hand combat, rules and regulations, communication, scenario-based training, perception and behavior, and psychological competencies).

3.2. Quantitative Results

We evaluated participants’ impressions of realism and user experience, along with the reflection on team communication performance and training objectives.
3.2.1. Realism and user experience

The trainees rated the system positively regarding ease of use (M = 4.4, SD = 0.6) and quality of learning (M = 4.4, SD = 0.5). The realism of the VR training was rated as moderately high (M = 3.8, SD = 0.6). The interactions in the VR system were also rated moderately high (M = 3.7, SD = 0.7). The added benefit through imagination of dangerous situations of the system was rated highly (M = 4.2, SD = 0.5). See Figure 3a for boxplots of the five scales.

![Boxplots of the five scales](image)

**Figure 3.** (a) Boxplots of the training experience questionnaire and (b) distribution of individual trainee–trainer differences.

3.2.2. Reflection

To evaluate how effective the system is in reflecting the team communication performance along the four identified factors for team communication and communication with the control center, we calculated the mean values per team on these factors and further calculated the mean difference to the respective trainer rating. We observed that overall team means, and trainer and team ratings in the four factors did not differ significantly (see Table 2), although there were substantial variations. Figure 4 displays the team mean ratings and the corresponding trainer rating on the four factors exemplary for four teams. Whereas some teams exhibited a very accurate reflection on their performance (Figure 1a), others misjudged their performance visibly (b). In many cases, teams systematically undervalued (c) or overestimated (d) their communication performance.

![Team communication performance](image)

**Figure 4.** Examples of team means (red) and trainer ratings (blue) on the four factors for team communication for four teams. (a) shows a high concordance between the team and trainer ratings, (b) shows a team rating itself higher and lower in two different factors than the trainer, (c) shows a team that consistently rates its performance lower than the trainer, and (d) shows a team rating its performance consistently higher than the trainer. Four factors were identified for team communication: (1) task distribution within the team, (2) precision of the team leaders’ instructions, (3) precise communication within the team, and (4) an overall evaluation of the communication performance.

Further analysis of individual differences between trainee ratings and trainer ratings revealed that 28% of trainee ratings matched the trainer’s rating for team communication and 23% for control center communication. Further, 35% and 38%, respectively, overestimated their performance by one point or more, whereas 37% and 39% underestimated their performance by one point or more. See Figure 3b for the distribution of individual trainee–trainer differences. Positive values on the x-axis represent an overestimation of trainees’
performance when compared to their trainers’ evaluation. Negative values represent an underestimation of one’s performance.

Table 2. Means and standard deviations of differences between team means and trainer ratings for the four factors.

<table>
<thead>
<tr>
<th>Task Distribution</th>
<th>Precision Lead</th>
<th>Precision Team</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>−0.13</td>
<td>0.17</td>
<td>0.40</td>
</tr>
<tr>
<td>Std</td>
<td>1.14</td>
<td>1.00</td>
<td>1.13</td>
</tr>
<tr>
<td>Min</td>
<td>−2.00</td>
<td>−1.75</td>
<td>−1.75</td>
</tr>
<tr>
<td>Max</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The trainers gave the answers to this question on a five-point Likert scale. To evaluate this question (“In your opinion, which training goals can be well-trained with VR?”), the average of the answers from the eight trainers was calculated. Particularly well rated were the use of tactical training (4.88), scenario-based training (4.75), self-defense training (4.63), communication training (4.38), and the training of psychological skills (4.25). See Figure 5 for an overview of all ratings and a ranking of training objectives for which VR is suitable.

Figure 5. Evaluation of the trainer question “In your opinion, which training goals can be well-trained with VR?”.

3.3. Qualitative Results

3.3.1. Trainees

The following are the inductive categories of the qualitative questions that emerged for the question: “Compared to conventional deployment training, to what extent do you think virtual reality supports communication training?”. We employed an inductive categorization methodology inspired by Mayring’s qualitative content analysis [56]. This approach allowed us to systematically evaluate open-ended questions and evolve topics naturally from the data rather than imposing preconceived categories.

The realism of virtual reality is identified as a particular advantage. The police officers interviewed indicated that communication can be trained more realistically using VR than traditional operational training (18 mentions). This realism can be attributed to a few essential factors in this regard. One factor highlighted by five participants is the simulation of unknown situations. With the help of virtual reality, participants already knowing the localities and exercises can be avoided (five mentions). Another factor identified is distracting factors such as distractions, noise, ambient sounds, or simultaneous speaking that can make communication difficult (four mentions).

Furthermore, a realistic environment was emphasized. On the one hand, this can be achieved by the above-mentioned disturbing factors, but other influences such as realistic premises, noises, people present and interacting with the environment, as well as feedback from the environment, also pay attention to this (eight mentions). Furthermore, time pressure, stress, and real-triggered emotions (each three mentions) emerged as factors for increased realism influencing communication.

Another topic is the positive effects of realism on communication training. According to the participants (12 mentions), virtual reality can significantly support communication
training. The unexpected situations can promote participants’ flexibility. Furthermore, the realistically presented scenarios encouraged the participants to communicate more with each other than in conventional training (five mentions); this includes promoting active listening (two mentions). During this, lack of communication can also be clarified (two mentions). Simulating stressful situations also makes it possible to train communication skills under increased stress levels (five mentions). This simultaneously illustrates how challenging communication is during stressful situations and ensures more effective training (four mentions). Thus, communication gains importance in this type of training, and the importance of communication can be demonstrated (five mentions).

Moreover, the versatility of VR is highlighted as positive. VR allows communication skills to be trained in versatile scenarios (five mentions). Not only can different spaces be simulated, including real existing spaces, but also, for example, pressure can be increased through fast-paced scenarios (two mentions). Furthermore, situations that would not be trainable in conventional training can be trained.

The AAR in VR is identified as an added value. The AAR emerged as a prominent factor in the evaluation of this question. Twenty participants explicitly highlighted the AAR as a significant advantage of VR as a communication training tool compared to traditional training methods (20 mentions). The capability to comprehensively record all VR training aspects, including positioning, tool usage, and other data, creates a digital twin simulation that captures every detail. This extensive recording, highlighted by 15 participants, offers an advantage over conventional training, which often relies only on video data captured from a limited number of cameras and angles. The VR-recorded data enable a comprehensive retrospective examination from various perspectives, encompassing general actions, movements, viewing angles, weapon orientations, and communication aspects.

Through this analysis, both positive and negative aspects, including communication, can be effectively illustrated and discussed. This facilitates a better understanding of mistakes and aids in self-recognition of errors, making it easier to correct them later (nine mentions).

3.3.2. Trainer

Six of the operational trainers explicitly stated that communication skills have a high priority in current operational training, as only with targeted communication can the teams succeed in the scenarios. However, it is noted that this always depends on the field of expertise or the type of training. In training with high realism, communication is of particular importance.

Essential factors that are evaluated in relation to communication are short, concise communication (six mentions). And communication should be reduced to essential information (six mentions). This is intended to help implement tasks in an appropriate time frame (one mention). Important communication channels that are evaluated include communication within the team with third parties with the control center (one mention). The evaluation also takes into account environments with various influences such as stress or loud ambient noise (one mention). Furthermore, self-reflection and critical assessment of one’s actions are considered essential competencies that should be included in the evaluation (three mentions).

As was already determined during the content analysis of the trainee questionnaires, the AAR is a particular added value of VR. The operational trainers also particularly emphasize this (six mentions). In particular, the visual support provided by video recordings is highlighted, allowing the participants to re-experience the scenarios from different perspectives and reflect on them without time pressure. This enables the participants to recognize mistakes on the one hand and understand them more easily on the other.

4. Expert Workshop

After conducting the field study and analyzing the results, we organized an expert workshop to discuss the result of the first study with experts and to gather additional
insights for answering RQ2 (Approaches and ideas for future VR systems for police communication training in high-stress operations). Two experienced HCI researchers who had also been involved in the field study planned and moderated the workshop.

During the workshop, expert statements and keywords from discussions were collected on Post-It notes, and then, organized into clusters on a flipchart by the two moderators. Clusters were grouped based on similar statements and topics. The findings were then shared with the group to generate further insights and gather ideas and initial approaches. In the workshop’s initial stage, the key findings of the field study were presented, and the study’s goals were explained. Specific results were not disclosed to prevent biasing the discussion. After this introduction, the discussion began, with the moderators following a guideline that included five key discussion points. The results of these discussions are summarized in this section and an overview is presented in Figure 6.

Figure 6. Overview and summary of qualitative feedback from the expert workshop.

The following key points were discussed: (1) What constitutes “good” communication from a police perspective?; (2) What are the specific considerations for communication training?; (3) What problems do trainers currently face in evaluating or providing feedback on communication skills?; (4) Is VR suitable for communication training focusing on operational training and why?; and (5) What forms of visualization and technologies could assist trainers in providing feedback to trainees?

4.1. Organization

The workshop occurred during a four-day police symposium on “Virtual Reality & Police”. More than 80 participants from twelve European countries gathered at this event to discuss trends, developments, and experiences related to VR in the context of policing. On the fourth day of the event, an expert workshop on “VR Training & Communication” was held, lasting for two hours. Eight participants signed up for the workshop; none of the eight participants were involved in the previous field study. The workshop’s topic and objectives were explained to all participants, and eight individuals voluntarily chose to participate.

4.2. Participants

Among the eight participants, six were from a law enforcement background (representing four different organizations) with extensive experience in training and operational training. One is from the Ministry of the Interior, responsible for the entire training and education area within the police authority for approximately 60,000 police officers. Two participants are experienced (more than ten years) police trainers in operational training and have already conducted VR training. Two other persons work in the media and tech area of the police authorities and are responsible for VR developments and content creation (such as 3D assets and scenario design). One person comes from a special unit and is responsible for training planning and development in this area. Two persons are not
enrolled within the police but a state security authority. These people are responsible for the development of technological innovations, with a particular focus on the development and use of XR solutions in the training area. All participants had prior experience with VR in operational training.

4.3. Results—Future Ideas and Approaches

In the evaluation and analysis of the discussion and the flipcharts produced, the following results can be noted.

4.3.1. Is VR Suitable for Communication Training with a Focus on Operational Training and Why?

All eight participants saw the potential for VR in communication training, even though current technical VR developments often focus on different areas (e.g., VR for driving simulations, VR for crime scene inspection, or decision-making training). Participants mentioned only a few concrete developments in research or currently on the market on communication training for operational training in virtual environments. In the field of communication training with VR, participants mentioned interrogation training, witness questioning, or general interaction with civilians as police officers. The participants mentioned three to four leading professional VR systems for scenario-based operational training. These systems primarily emphasize tactical training, the use of police tools, and decision management rather than communication training. Therefore, the experts here see a need for improvement in the industry and would like the providers to focus more on communication training.

4.3.2. What Are the Specific Considerations for Communication Training?

Relevant for all eight participants was a simple and continuous recording of all (verbal) forms of communication as well as user-friendly access to analyze these recordings. It was essential for one trainer to mention “...we are trainers and not technicians...so everything has to be simple and quick without a lot of knowledge...”. One aspect agreed upon by all participants was the legal component and the traceability of police communication. In real operations, all radio transmissions (including those within and between the team and the control center) are recorded and may become relevant retrospectively. For instance, radio transmissions serve as evidence in court or can be used in complaints against the police. Therefore, communication during an operation also serves a formal record-keeping function, and this should be considered in training or made clear to trainees.

4.3.3. What Constitutes “Good” Communication from a Police Perspective?

The relevance of different communication paths (within the team, to the control center, etc.) was immediately brought up for discussion. Communication on each path is evaluated based on different parameters, and different factors are relevant. Police officers must use “user-centered language” during missions, meaning they must know who they are communicating with and adapt to the context or situation. Examples given here were communication with special groups such as children or people with unique roles such as witnesses or perpetrators. All participants mentioned that the VR scenarios must reflect these different groups of people.

During the workshop, an example was given (by a trainer) of the “use of specialized vocabulary” when communicating with the control center or the team. For instance, when communicating within the team, “vague” location descriptions like “I see the suspect on the left side approximately” should be avoided, and precise technical information like “Suspect at 10 o’clock” should be used. This vocabulary can save time and ensure correct information is conveyed (“the same team language”). Particularly in high-risk and stress training, all participants mentioned “time-saving” and “clear instructions” as essential criteria for communication. Six participants mentioned that a distinction must be made between the content of communication and the way it is communicated. For example,
the expressiveness of the communication must be evaluated. As an example, the difference between the sentences “please show me the vehicle documents” versus “drop the weapon” was mentioned. This means that the context, the situation, or the task of the police officer when communicating must be grasped by the trainer and included in the evaluation and feedback.

In summary, it can be asserted that effective communication within the police sector is inherently complex. Communication demands adaptability to the specific circumstances, the various roles involved, and the specific objectives pursued by police officers.

4.3.4. What Problems Do Trainers Currently Face in Evaluating or Providing Feedback on Communication Skills?

One issue that all participants raised is the current difficulty in evaluating and analyzing communication quality. In operational training, only one trainer typically oversees the training and provides feedback to the participants. This trainer must address various training aspects (such as tactical behavior, use of operational tools, etc.), and communication is often just one of these factors. It is often challenging for the trainer to keep up with communication, given the many activities happening simultaneously (e.g., brief radio communication with the control center by one person while others in the team are talking to each other). As a result, communication may not continuously be accurately tracked, leading to less comprehensive feedback. Another issue is the factor of time. If communication problems arise at the beginning of a scenario, the trainer must remember or note these issues for the feedback session at the end of the training.

During the workshop, the advantages of VR were emphasized in this context, primarily due to the possibility of recording all actions and communication. All participants recognized the potential for future developments of “How can VR or compatible technologies assist or support the trainer?”.

4.3.5. What Forms of Visualization and Emerging Technologies Could Assist Trainers in Providing Feedback to Trainees?

In the final question posed to the workshop participants, initial ideas were mentioned and further developed collectively. The following core themes regarding ideas for visualization and emerging technologies were identified.

**Visualization of Communication:** Communication could be visualized in different forms, for example, by using a network diagram (https://www.data-to-viz.com/graph/network.html; accessed: 14 September 2023), chord diagram (https://www.data-to-viz.com/graph/chord.html; accessed: 14 September 2023), streamgraph (https://www.data-to-viz.com/graph/streamgraph.html; accessed: 14 September 2023), or word clouds (https://www.data-to-viz.com/graph/wordcloud.html; accessed: 14 September 2023). Communication paths (between the team, from the team to the control center, etc.), including word count, communication duration in seconds, and frequency, could be represented as a network graph. Similarly, chord diagrams could be useful to identify who communicated with whom. This would allow trainers to see communication frequencies and pathways at a glance; e.g., no communication occurred with the control center, 45 s of communication within the team, but only between person A and person B, despite there being four people on the team, etc. For each team member, a stream graph could visualize the communication of the individual participants over time. For example, each participant is assigned a color and topics/keywords (including snippets of original text for context), and events/milestones can also be displayed. Moreover, the semantic content of a team communication could be summarized in word clouds as shown, for example, for analyzing court cases [57].

Also, solutions for visualizing and exploring communication in other areas could be used, e.g., TalkTraces used for visualization of verbal communication in meetings [58], Convvis for exploring blog post conversations [59], or ConToVi for visualization of multi-party conversations [60].
Timeline and event view: Another aspect mentioned in the discussion by one of the participants is the temporal sequence of main events in communication training. Based on scenario 2 from the field study (which was presented at the beginning of the workshop), the participant proposed the idea of defining a timeline of the most relevant sequences and events. The reasoning behind this idea is that at each of these events, a different communication path becomes appropriate, and the communication objectives vary. For example, it was mentioned: “...when the team arrives at the scene, it is important to define a strategy within the team for the next steps and then inform the command center about the next move...”.

This idea was deemed relevant by all eight participants, and within the group a shared approach was discussed. Based on scenario 2 from the field study, the following key events were extracted: (1) Arrival at the scene of the incident, (2) initial encounter between the police team and uninvolved individuals, (3) confrontation with perpetrator 1, and (4) confrontation with suspect 2. These four events should be defined in advance in the VR system as key events, and the system should automatically recognize when communication parameters are relevant for each event segment. For example, the system should tally the frequency of communications with the command center upon arrival at the scene (e.g., the command center was contacted via radio three times, etc.) or the number of spoken words within the team during the event. At the end of the training scenario, these results should be visualized for the trainer as a dashboard, providing quick key information about each sequence or event.

In the user interface, the trainer sees a timeline, and the defined sequences (e.g., the first encounter with the perpetrator) are visually highlighted. Corresponding to the sequences, relevant information for each sequence is displayed (e.g., frequency of contact with the control center, number of words spoken within the team, etc.). As benefits mentioned by the workshop participants, this allows trainers to receive direct feedback or make comparisons (for example, with other teams or previous sessions). It also enables quick navigation within the recorded VR videos to essential training events.

Creation of key performance indicators (KPIs): In conjunction with graph visualizations, KPIs help trainers make quick comparisons. Trainers should be able to determine how the current training team compares to previous teams (for example, the number of radio transmissions to the control center). These KPIs should be easy for the trainer to understand and follow. However, it was essential for all participants that KPIs should support, not replace, feedback from the trainer. In other words, the trainer views the KPIs and can use them, but a qualitative evaluation should be conducted by the trainer and not the system.

Artificial intelligence (AI) / learning models: Another aspect mentioned was the future use of long-term data and qualitative classification by experts. This means that if VR training becomes more prevalent in the future and allows for the storage of all communication information, deductions and learning models can be developed, and KPIs can adapt accordingly. Furthermore, it was mentioned that AI approaches could potentially be employed to personalize VR training, particularly in communication training. Specific desires were expressed, such as achieving a “human-like” communication experience with non-playing characters (NPCs). This entails NPCs engaging in highly realistic verbal and nonverbal communication with the trainees.

Analysis of voices: Integrating voice analysis techniques into VR police training introduces a novel dimension for assessing trainees’ engagement and responsiveness. By dissecting the acoustic attributes of voices, the trainers can reveal invaluable insights into emotional states and interpersonal interactions within simulated scenarios. Furthermore, the systematic examination of vocal patterns may facilitate the development of personalized feedback mechanisms, allowing trainers to tailor interventions to the unique needs of individual learners.
5. Discussion

In the following section, we discuss and reflect on the results of the two research questions.

5.1. RQ1: How Effective Is VR Technology in Enhancing Communication Training for Police Officers in High-Stress Operational Scenarios?

The quantitative and qualitative results of the field study, and the discussions in the expert workshops, show a positive trend that VR is a suitable tool for training police communication if factors such as realism and immersion are given in the VR system. The support of evaluation of communication training is highly relevant for trainers. Communication influences the outcome of police operations significantly [2,3] and the support of evaluation of communication training is highly helpful for trainers.

The results of our study indicate generally positive feedback from trainees regarding their experience with the VR training system. Specifically, trainees rated the system favorably in terms of ease of use (M = 4.4, SD = 0.6) and the quality of learning (M = 4.4, SD = 0.5). These findings suggest that trainees found the VR system to be user-friendly and effective in facilitating their learning process.

Regarding RQ1-A and the realism of the VR training, the ratings were moderately high (M = 3.8, SD = 0.6). While not achieving the highest level of realism, this level of realism is still noteworthy, indicating that trainees perceived the VR environment as sufficiently immersive and believable for training purposes. This is a good indication as realistic training scenarios are designed to prepare for real police operations, and realistic training scenarios are an important factor for adequate communication training [5,11,28].

The assessment of interactions within the VR system also yielded moderately high ratings (M = 3.7, SD = 0.7), suggesting that trainees found the interpersonal aspects of the VR experience to be engaging and interactive. One noteworthy finding was the high rating of the added benefit through the imagination of dangerous situations (M = 4.2, SD = 0.5). This suggests that the evaluated VR system effectively engaged trainees in scenarios involving potential hazards, enhancing their training experience by immersing them in challenging situations. This is a step towards overcoming the lack of realism in police training communication [5].

Similar insights are evident in the qualitative data, as the heightened sense of realism experienced during VR training was frequently highlighted. Trainees emphasized that communication training can be conducted more realistically in VR than in traditional operational training. This is because real-world operational training often takes place in classrooms or empty halls. Or, there are special training areas with flexible walls and living facilities. However, more complex scenarios (such as a school, railway station, or a market) often cannot be represented due to available resources. VR allows for the simulation of unfamiliar and unpredictable scenarios, preventing participants from relying on prior knowledge of locations and exercises. This feature was highlighted as a key advantage.

In VR training, realism is further enhanced through the recreation of lifelike environments, which is a significant advantage [24,33,34]. This involves not only replicating distracting factors but also incorporating realistic settings, ambient noises, the presence of people, and interactions with the environment. Feedback from the environment also contributes to the sense of realism. Participants acknowledged that VR can effectively replicate challenging conditions, including distractions, noise, ambient sounds, and simultaneous conversations that often occur in real-life situations, making communication training more authentic. VR training allows introducing unexpected and unpredictable situations, and thus, fosters adaptability and flexibility among trainees. This adaptability is a critical component of effective communication, particularly in dynamic environments. Participants’ feedback underscores that virtual reality significantly supports communication training by promoting flexibility, enhancing communication, offering training in stressful conditions, and elevating the importance of effective communication. These insights highlight the potential of VR as a valuable tool for improving communication skills, particularly in
the challenging and dynamic contexts often faced by police officers. This is a significant potential as communication significantly influences the outcome of police operations [2,3], and thus, communication is essential for the collaboration and success of first responder teams [6,44,45].

Regarding RQ1-B, i.e., the facilitation of effective reflection on communication, our analysis revealed interesting dynamics. This is in line with Staller et al. [7], who highlighted the underestimation of one’s blind spots and the importance of reflection. The trainee and trainer ratings on the four identified factors for team communication and communication with the control center did not significantly differ on average. However, there were substantial variations among teams. Some teams demonstrated a highly accurate reflection on their performance, while others exhibited visible discrepancies between their self-assessment and the trainer’s assessment. Further examination of individual differences in trainee and trainer ratings showed that a significant portion of trainees either overestimated (35–38%) or underestimated (37–39%) their own communication performance by one point or more. Only 28% of trainee ratings for team communication and 23% for control center communication matched the trainers’ ratings. These findings indicate that while the VR system is effective in training, trainees may have varying degrees of accuracy in assessing their performance.

Feedback from the eight trainers indicated high ratings for various training applications, with particularly favorable scores for use in tactical training (4.88), scenario-based training (4.75), self-defense training (4.63), communication training (4.38), and the training of psychological skills (4.25). These trainer ratings affirm the system’s versatility and effectiveness across multiple training domains, underscoring the potential for VR-based training as a valuable tool in various training contexts [10,24,30,31]. Moreover, in the qualitative insights, AAR emerged as a central component in evaluating VR as a communication training tool, as currently, there is not much focus on teaching and reflecting communication in the training of police officers [7,50]. Participants (trainer and trainees) highlighted the value of recording training sessions in VR, allowing for retrospective analysis from various perspectives. This feature facilitates a detailed examination of scenarios, actions, and communication, offering a unique learning opportunity. The AAR not only aids in understanding mistakes but also encourages self-recognition and correction, enhancing the overall learning experience.

In conclusion, and as an answer to RQ1, the findings from both RQ1a and RQ1b collectively demonstrate that VR technology is not only a viable but also a valuable method for advancing communication training for police officers. By providing realistic, immersive scenarios alongside effective mechanisms for reflection and feedback, VR creates a dynamic training environment conducive to significant development and performance enhancement of communication skills.

Throughout debriefing sessions and numerous one-on-one conversations with trainers, a consistent emphasis was placed on the notion that virtual reality (VR) can serve as a valuable tool to support and expand training capabilities, but it cannot wholly substitute real-world training experiences [15].

5.2. RQ2: What Design Ideas or Implications Are Relevant for Future Developments?

From the qualitative statements of the study and especially from the results of the expert workshop, the following implications for the derivation of ideas and approaches for future systems emerged.

**Feedback approaches for usage after the training:** Reflection on the results or feedback by the trainer at the end of a training session are considered highly relevant; however, appropriate feedback modalities are currently missing [11]. A statement by an expert during the workshop, “...without the feedback by the trainer, training is pointless...no matter whether VR or real...”, underlines this assumption. For all eight participants of the expert workshop, the AAR was, therefore, a central aspect for future developments.
It should be noted, based on the researchers’ observations during the field study, that two types of feedback occurred during the training sessions: the mentioned AAR at the end of each session, following the completion of a scenario, and direct feedback provided during the training. However, this direct feedback only happens when there are severe mistakes by the trainees. This is the case, for example, if at the beginning of a scenario, the team needs too much time to decide on a strategy and group division (because in a real operation such as a rampage at a school, every second until the operation starts decides between life and death). The trainer then interrupts the training session, immediately points out the mistake, and restarts the training session after receiving feedback. However, this could only be observed very rarely.

**Real-time feedback approached during the training:** The workshop discussions showed that it is often difficult for trainers to correctly follow and understand the communication from the trainees (for example, when four people are talking in confusion, loud background noises such as gunshots are heard, parallel communications between the team and the control center are taking place, etc.). The workshop showed a strong need for design solutions for future VR systems. For example, communication could be displayed in real time using a network diagram, as feedback is especially valuable if visually supported [7,29,40]. This shows who is currently communicating with whom (team member A to team member B or team member C to the control center, etc.). This real-time visualization would support the trainer and assist in future training.

**Assistive systems for the trainer:** In the expert workshops, the problem of “where to visualize these results” was also mentioned. The trainers must focus on the trainees and observe them, and therefore, the additional information has to be localized or contextualized. Ideas discussed here were, for example, the development of a wearable device for the trainer (like a display on the arm to briefly look up relevant information) or the use of augmented reality (AR) solutions. Here, one of the approaches was for trainers to wear AR glasses and have relevant context information displayed (such as the network diagram or KPIs over the head of the trainees). We see this as an interesting approach for future research.

Another aspect mentioned by the experts is the time problem in police training. Often, there is not enough time for feedback at the end of a session in the AAR. Trainers must focus on the most important key points and decide very quickly which actions or events to feedback. Here, the need for an assistive system or visualization and calculation of indicators was mentioned in the workshop [61]. Concrete approaches were, for example, keyword identification, which can be used to compare used words with standard police vocabulary—which means were the concrete vocabulary words used within the communication?). The need was for an automated evaluation and, in the case of identified problems in the training sessions, a direct jump in the recorded VR video to the scene to show it directly to the trainees.

In general, all workshop participants mentioned the possibilities of VR as a reflection tool for communication training, and the experts see an advantage of VR compared to conventional training. This is because all events or any communication as a single channel are recorded and can be replayed [7,15,24]. VR also allows the scene to be shown from all angles and zoomed into relevant areas when playing back the videos. This supports the trainers to show training errors better or to mirror the behavior or communication directly to the trainees [15]. In summary, concerning RQ2, we identified potential future directions and implications aimed at improving AARs. These include incorporating communication visualizations, developing communication KPIs for more effective evaluation, and creating AR devices to enhance the trainer’s perspective during training sessions.

### 5.3. Limitations and Future Research

There are certain limitations to be mentioned. As the field study was conducted ‘in the wild’ [54,55], there are limitations in terms of the scope and content of the data collected. The operational training for the police was strictly timed, allowing minimal time between
and after scenarios for retooling equipment and completing questionnaires. In addition, the research extends beyond the study of communication to other aspects of the training, which further exacerbated the constraints on time. This limitation had to be considered in both the data collection process and the development of the questionnaires. Consequently, we did not use standard questionnaires and were only able to include a limited number of questions.

Furthermore, the field study was conducted with only one police agency in one country, potentially introducing bias due to cultural factors or varying regulations within police training. The results should be replicated with a similar setup in another country, with a different police agency.

It is also important to mention that the presented results always focus on operational training and training for high-stress scenarios. Additionally, the emphasis in this work was placed on two communication pathways: team communication and communication from the team to the control center.

Based on these limitations, the first objectives for future research are already emerging. The focus will be on conducting a comparative study involving multiple countries and expanding the communication pathways (communication between police and civilians and between police and perpetrators).

In this study, only verbal communication was examined. However, the literature strongly emphasizes that nonverbal and para-verbal cues significantly influence human communication [6]. An investigation into these aspects could enhance understanding of police communication. Further research should consider nonverbal and para-verbal communication, which is crucial in police operations. Examples include tactical signals within teams and nonverbal behavior during suspect apprehension. We identify opportunities VR offers, such as analyzing nonverbal communication using facial recognition technologies and tracking devices for subtle finger movements.

Another central research approach we see is the analysis of the voice [62] (not just the content of spoken communication). For example, voice analysis could be used to measure emotional factors (e.g., stress), providing valuable input for trainers. Additionally, factors like speaking speed, word or sentence emphasis, and clarity could be intriguing research questions. These results could be analyzed using AI-driven statistical methods, eventually leading to the creation of optimal learning models that support trainers in real-time feedback and reflection processes.

It is essential to acknowledge that VR should complement or enhance real-world training rather than replace it, given the presence of certain limitations and individual differences in self-assessment. Addressing technical limitations and enhancing physical interaction within VR environments could enhance its effectiveness in communication training.

6. Conclusions

Communication skills are fundamental to the performance of police officers [2,3] and to learn them adequately conscious and regular training is necessary. The assessment and evaluation of communication skills represent a highly relevant research area. This work has shown that VR offers significant potential in this regard and has been well received by trainers and trainees.

Our findings suggest that VR can be a valuable tool for communication training within high-stress operational contexts, especially for police communication. When creating communication training in VR, it is essential to focus on realism, reflection, and repetition. VR is a suitable tool that can ensure these factors. VR supports recording and enables analysis, which positively affects reflection. When realism and immersion are adequately provided within the VR system, trainees benefit from engaging, adaptable, and realistic training experiences.

The versatility of VR and its capacity to facilitate the AAR and the evaluation of communication training make it a relevant tool for trainers aiming to enhance communication skills in dynamic environments.
The presented field study and expert workshop have generated innovative ideas and approaches that shall be pursued in future work. On one hand, assistive systems for trainers, particularly relevant in the context of police training, will be explored. For instance, AR glasses could be developed to provide trainers with real-time information on communication KPIs directly during training sessions. On the other hand, the exploration of diverse visualization forms for AAR will be a priority, focusing on identifying methods that effectively support trainers in feedback delivery. This includes assessing which visualization strategies can provide substantial benefits, and dedicated studies will be initiated to explore these findings further.

Additionally, visualizations for communication among different individuals and roles represent promising design directions for future systems. Moreover, the realm of nonverbal communication within VR training presents a compelling area for further investigation, especially due to ongoing issues with finger-tracking technologies. Efforts will be directed towards developing precise methodologies for the measurement and interpretation of gestures by trainers. Furthermore, AI-supported analysis of vocal elements will also be pursued, focusing on factors such as tonality and loudness, to develop systems that facilitate automated evaluations and enhance interaction fidelity in simulated environments.

Overall, VR represents a valuable addition to future training efforts within operational contexts, offering the potential to enhance communication skills and prepare police trainees for the challenges they may encounter.

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