AVALANCHE RESCUE VR: IMMERSIVE VIRTUAL REALITY TRAINING FOR COMPANION RESCUE

Norbert Lanzanasto[1]*, Christoph Sitar[2], Anna-Lena Hetzenauer[3], Christopher Marquardt[1], and Paul Mair[4]

[1] *Avalanche Warning Service Tyrol, State of Tyrol, Innsbruck, Austria*
[2] *MEDIASQUAD, Innsbruck, Austria*
[3] *Department of Computer Science, University of Innsbruck, Innsbruck, Austria*
[4] *MC2ALPIN, Oberhofen, Austria*

ABSTRACT: Companion rescue remains the single most critical factor in surviving avalanche burials, where the first ten minutes offer a survival probability of approximately 90%. However, stress, panic, and lack of procedural practice often degrade real-world rescue performance. While physical field exercises are irreplaceable, they are logistically intensive, weather-dependent, and rarely repeated frequently enough by the general public. To bridge this training gap, the Avalanche Warning Service of the State of Tyrol, in cooperation with MEDIASQUAD and MC2ALPIN, developed 'Avalanche Rescue VR' (originally 'Notfall Lawine VR' in German), a free, highly immersive Virtual Reality application available in the Meta Store. This paper presents the pedagogical design, procedural workflow, and empirical findings from a database of 515 tracked sessions. The application guides users through a linear rescue sequence: from packing a virtual backpack at home, conducting a trailhead transceiver check, executing an emergency call, to performing signal, coarse, and fine search phases, culminating in probing and shoveling. Trainee performance was analyzed using three data streams: static session parameters, high-frequency spatial tracking, and event-based triggers. Results reveal common procedural omissions, such as 75% of trainees failing to check their mobile emergency app prior to departure, alongside highly successful procedural acquisitions, such as the systematic implementation of the 'airport approach' search technique (where transceiver height systematically reduces from 1.13 m to 0.80 m close to the victim). This study demonstrates that VR serves as a low-barrier, failure-tolerant complement to field exercises, reinforcing sequential memory, cognitive schemas, and stress-resilient action paths.

KEYWORDS: Avalanche rescue, Virtual Reality, companion rescue, procedural training, user analytics.

1. INTRODUCTION

In the event of an avalanche burial, the immediate rescue by companions represents the single most decisive factor in determining survival. Empirical data indicates that buried victims rescued within the first ten minutes exhibit a survival rate of approximately 90%. After this critical golden window, the survival probability dropping to about 30% after 30 minutes (Rauch et al., 2024). Despite widespread public awareness of these statistics, many winter backcountry recreationists exhibit insufficient proficiency in executing companion rescue under emergency stress. Effective rescue demands not only physical stamina but also strict adherence to sequential, highly structured safety procedures and precise technical manipulation of emergency equipment.

Traditional avalanche safety education relies heavily on classroom lectures and physical field courses. While field-based practice remains irreplaceable for physical and sensory skill acquisition, it suffers from severe logistical constraints. Field courses require significant snow cover, favorable weather, substantial travel, and extensive preparation by instructors to bury beacons and set up realistic rescue fields. Consequently, winter professionals and recreational users alike—including skiers, snowboarders, snowshoers, and snowmobilers—rarely rehearse these skills more than once per season, if at all. This lack of regular rehearsal directly results in low procedural automaticity and decision-making errors during real-world, high-stress avalanche

* *Corresponding author address:*
Norbert Lanzanasto, Avalanche Warning Service Tyrol, Wilhelm-Greil-Strasse 17, 6020 Innsbruck, Austria;
tel: +43 512 508 7730
email: norbert.lanzanasto@tirol.gv.at

incidents.

To address this critical training frequency gap, the Avalanche Warning Service Tirol, in collaboration with the immersive technology agency MEDIASQUAD and MC2ALPIN, designed and developed 'Avalanche Rescue VR'. The application is available globally as a free download in the Meta Store, making immersive safety training accessible to anyone with a standalone virtual reality headset and a 4x4 meter space. Rather than attempting to replace real-world physical training, the application was engineered to act as a low-barrier, highly repeatable cognitive and procedural addition, allowing trainees to reinforce rescue sequences at home, in a hotel, or on a mountain hut the evening prior to a backcountry tour.

2. SYSTEM DESCRIPTION AND PROCEDURAL WORKFLOW

Avalanche Rescue VR is built using Virtual Reality technology, utilizing a head-mounted display (HMD) and dual motion controllers to place the user in an active, fully interactive three-dimensional environment. This technical setup allows the trainee to naturally look around, walk physically within their boundaries, and perform manual tasks—such as packing gear, adjusting transceiver buttons, and handling a probe—using natural hand gestures. The pedagogical core of the simulator is structured around a linear, chronologically accurate, and procedurally strict safety sequence that represents a complete backcountry touring day and ensuing emergency rescue. To accommodate different user experience levels, the simulator features two distinct operational settings: a beginner mode and an advanced mode. In the beginner mode, the system provides comprehensive visual instructions, highlighted hints, and step-by-step guidance, allowing novice users to learn companion rescue protocols from scratch. In contrast, the advanced mode removes all instructional prompts and hints, providing a realistic assessment environment that tests the trainee's procedural automaticity and stress-resilience under time pressure.

2.1 *Backcountry Tour Preparation and Gear Selection*

The simulation begins in a virtual domestic environment (the virtual garage) where the trainee is tasked with preparing for a winter backcountry ski tour by packing a virtual backpack. Trainees must physically interact with and select items from shelves, distinguishing between mandatory safety equipment and secondary equipment. In this module, the system does not restrict incorrect packing decisions, allowing trainees to make critical preparation errors. For example, one of the available transceivers has a low battery; however, checking its power status is not enforced by the system, meaning a trainee can make a high-consequence pre-departure check oversight that can lead to search failures later on. During this preparation phase, the user's mobile phone rings, teaching them how to interact with digital devices in the virtual environment. On this phone, trainees can optionally install a specialized emergency app. If installed, this app can be used to place an automated, location-enhanced emergency call later in the scenario; otherwise, they must execute a standard phone call under cognitive pressure. Additionally, a companion leaves a voicemail message on the mailbox, sharing crucial information about the local avalanche forecast and hazard levels that the trainee must listen to. Essential rescue items include an avalanche transceiver, a probe, and an avalanche shovel. Secondary but highly critical gear includes a first-aid kit, and a bivy sack. Trainees must load their equipment, pack their ski boots, and complete a trailhead safety checklist (Lanzanasto et al., 2025).

2.2 *Trailhead Routines and Group Transceiver Check*

Upon completing the packing module, the scene transitions to a trailhead parking lot alongside virtual touring companions (Dominik and Lisa). Here, the simulator enforces standard pre-tour safety protocols. Critically, trainees must perform a standard avalanche transceiver group check before departing. They must switch their own device to 'Search' mode and verify that their companions' transceivers are transmitting correctly, ensuring all devices are operational prior to setting foot on the snow.

2.3 *The Emergency Rescue Chain and Search Phases*

The tour commences with a movement sequence that is suddenly interrupted by a stress-inducing avalanche release cutscene. The trainee witnesses their companion, Lisa, being swept away and buried under the snowpack. The simulator immediately initiates an emergency countdown timer and requires the user to execute the complete emergency rescue chain under cognitive pressure:

- Emergency Call: Trainees must immediately place an emergency call to professional services, choosing whether to use a direct telephone call or a specialized digital mobile warning app.
- Signal Search: After confirming their own transceiver is switched to 'Search' mode, the user must execute a systematic, wide zig-zag search trajectory across the avalanche debris field to capture the initial transmitting signal of the victim.
- Coarse Search: Once a signal is received, the transceiver display provides visual distance and directional arrow guidance. Trainees must follow the flux-line trajectory while moving rapidly but deliberately.
- Fine Search: At a displayed distance of less than 10 meters, directional arrows disappear. The trainee must slow down, bend over, and move the transceiver close to the snow surface, executing a systematic grid search (cross-like pattern) to identify the point of lowest displayed distance.
- Systematic Probing: Using the physical controller, trainees plunge a virtual avalanche probe into the snowpack. The probe must be thrust at a perpendicular 90-degree angle relative to the slope, expanding in concentric circles outward from the point of lowest transceiver distance until a hit is confirmed.
- Shoveling: Once the probe strikes the target, the trainee starts excavation. Because the physical resistance and ergonomics of digging cannot be realistically simulated in VR, the scenario transitions immediately after initial shoveling begins. The scene cuts as a rescue helicopter arrives, presenting the trainee with comprehensive performance statistics—such as total search time and critical errors—to conclude the simulation run.

3. VR AS A COMPLEMENT TO FIELD TRAINING

The implementation of Avalanche Rescue VR highlights distinct cognitive and educational advantages, framing virtual training as a powerful complement rather than a replacement for physical field exercises. Physical courses are essential for experiencing the heavy physical exertion of shoveling, the resistance of compacted avalanche snow, and real-world environmental factors such as wind and cold. However, Virtual Reality excels in areas where physical training is logistically restricted or instructionally weak This symbiotic relationship is supported by empirical master's research at the University of Innsbruck, which confirmed that VR environments are highly effective for hardwiring sequence memory and spatial safety workflows, but serve as a low-barrier complement rather than a physical substitute for field training (Hetzenauer, 2025).

- Zero Setup and Unrestricted Repeatability: A physical avalanche exercise requires hours of setup, hiding transmitters, and smoothing out snow trails between runs. In VR, a complete rescue scenario can be reset and randomized with a single button press. This allows trainees to experience dozens of runs and diverse burial configurations in a single afternoon.
- Safe Failure and Cognitive Schema Hardwiring: In real-world exercises, instructors often intervene before major mistakes occur to keep the class on schedule. VR provides a highly tolerant environment for failure. If a trainee forgets to pack a probe or switches off their transceiver, the simulation continues, allowing them to experience the catastrophic consequences of their omissions. This safe failure mechanism deeply reinforces correct cognitive schemas and action sequences in memory.
- Procedural Automaticity: High-stress emergencies cause severe cognitive narrowing and panic, which can disable logical thinking. By repeating the linear workflow of the virtual rescue chain

multiple times, the exact order of operations (Emergency Call -> Signal Search -> Coarse Search -> Fine Search -> Probing -> Shoveling) is hardwired as a stress-resilient procedural routine.

• Lowering Barriers to Safety Education: Recreational winter sports enthusiasts who might never sign up for a weekend-long physical field course can easily download the app and practice basic rescue procedures at home, significantly broadening the reached audience for avalanche safety education.

4. THE EMPIRICAL PERFORMANCE TRACKING ENGINE

Beyond its primary role as a pedagogical tool, Avalanche Rescue VR operates as a sophisticated diagnostic and scientific research platform. The simulator features a comprehensive performance tracking engine that records fully anonymized trainee behavior during every training run. When the HMD is connected to the internet, the tracked parameters are automatically compiled into a lightweight JSON format and securely transmitted to the data infrastructure provided by the State of Tyrol. This database allows safety researchers and educators to systematically diagnose common behavioral errors and assess training efficacy.

The tracking engine continuously captures three distinct categories of data streams:

• Fixed Session Parameters: Recorded once per run, these parameters establish the overall context, including total session duration, individual module completion times, specific binary decisions (e.g., whether the transceiver check was skipped), the exact inventory of packed gear, and the difficulty setting.

• Regularly Sampled Spatial Data: Sampled continuously at high frequencies, this stream tracks the precise three-dimensional coordinate trajectories (X/Y/Z) of the player's headset and motion controllers. It simultaneously logs live transceiver parameters, including display distance, directional arrows, orientation angles (declination and inclination), and the physical height of the LVS device above the snow surface.

• Event-Based Parameters: Triggered only upon specific actions, these parameters document distinct milestones, such as the exact timestamp of emergency calls, teleportation movements, scene transitions, and probe stick entries (including exact depth and entry angle relative to the perpendicular 90-degree ideal).

5. EMPIRICAL RESULTS AND BEHAVIORAL DIAGNOSIS

A systematic analysis was conducted on a dataset containing 515 fully recorded, anonymized trainee sessions. This empirical database provides unprecedented scientific insight into how recreationists behave during preparation and emergency rescue operations, highlighting specific areas of cognitive strength and critical behavioral weaknesses.

5.1 *Frequent Trainee Errors and Omissions*

The analysis of preparation and rescue parameters reveals a stark contrast between physical preparation and cognitive safety checks. Trainees exhibited high compliance with basic physical tool requirements: only 4% of trainees failed to pack a shovel, and only 5% omitted packing a probe. Similarly, emergency communication was highly prioritized, with only 3% failing to place an emergency call during the scenario. However, cognitive preparation and emergency planning represented the weakest link in the safety chain. A staggering 75% of trainees (389 individuals) completely omitted checking their mobile emergency and avalanche warning app prior to setting out (Figure 1). Furthermore, secondary safety gear was frequently neglected, with 10% failing to pack a bivy sack (53 trainees) and 9% omitting a first-aid kit (47 trainees).

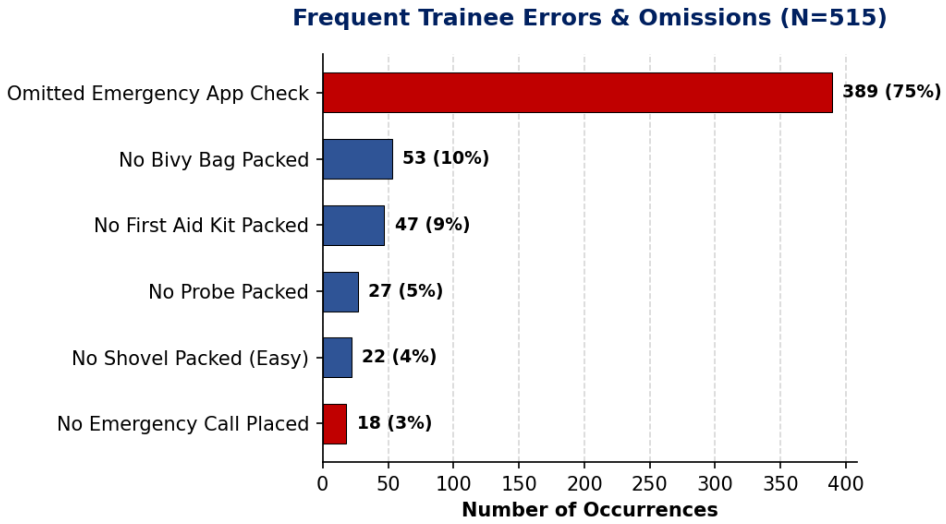

Figure 1: *Frequent trainee preparation errors and procedural omissions recorded across a database of 515 sessions.*

Pedagogically, this behavioral pattern—where physical gear is packed correctly but emergency app planning is largely ignored—demonstrates a crucial 'so what' for avalanche safety educators. Trainees prioritize immediate, tangible rescue gear but remain highly vulnerable to planning failures. If a rescue team is forced to spend the night on the debris field due to severe weather, the omission of a bivy sack or first-aid kit can prove fatal, underscoring the necessity of highlighting preparation discipline in classroom safety courses.

5.2 *The LVS Height Control and 'Airport Approach' Compliance*

A critical technical skill in fine search operations is the 'airport approach'. As a rescuer approaches a buried victim and the distance display drops, they must slow down and lower the transceiver directly onto the snow surface. To determine if the simulator successfully teaches this technique, the height of the virtual LVS device above the snow pack was analyzed against the display distance to the victim (Figure 3).

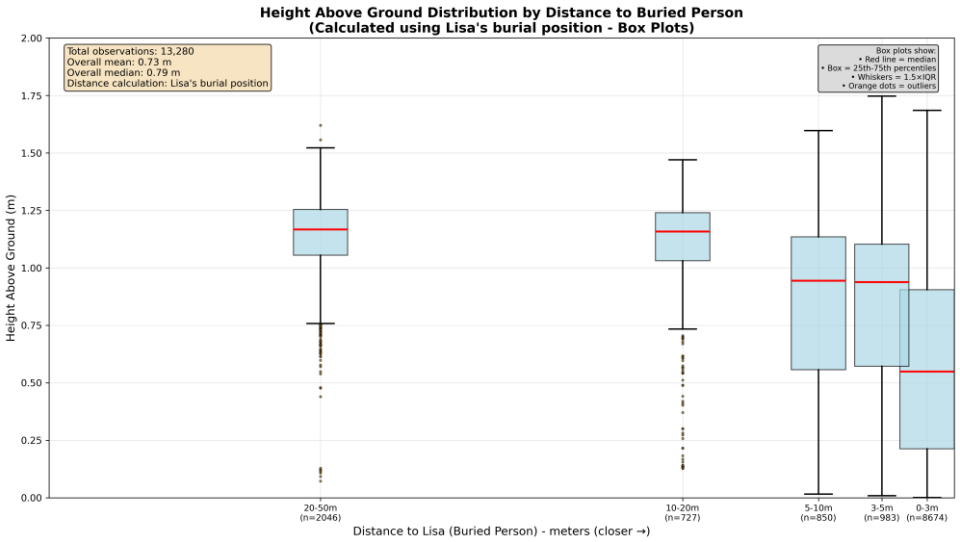

Figure 3: *LVS transceiver height above the snow surface as a function of display distance, demonstrating successful compliance with the 'airport approach' technique.*

The data demonstrates a clear, statistically significant downward trajectory in mean transceiver height. This clear downward trend indicates successful behavioral acquisition, proving that the immersive

visual and haptic feedback of the simulator effectively guides trainees to perform correct spatial fine search maneuvers without explicit instructor intervention.

5.3 *Search Trajectory and Signal Search Efficiency*

Continuous X/Y/Z coordinate tracking provides the spatial foundation to visualize and evaluate trainees' signal search efficiency across the virtual avalanche field. Because a standard signal search mandates a systematic, wide zig-zag pattern to ensure complete coverage, logged trajectory data can be utilized in future investigations to assess procedural adherence. Such analyses could quantify the prevalence of chaotic wandering paths versus structured coverage, measure delays in establishing the initial signal lock, or identify risky direct-line rushing that could bypass deeply buried victims outside the search-strip width.

6. DISCUSSION AND FUTURE DEVELOPMENTS

The empirical findings generated by the Avalanche Rescue VR tracking engine have substantial practical implications for avalanche safety education. Traditionally, avalanche course instructors could only evaluate the performance of a single student at a time, relying on qualitative, subjective observations. The ability to automatically capture high-fidelity spatial and behavioral data across hundreds of sessions allows safety organizations to perform rigorous behavioral diagnosis. For instance, the discovery that 75% of trainees fail to check mobile warning apps highlights a critical blind spot that instructors must explicitly target during theoretical classroom and physical field courses.

Looking ahead, several potential extensions could further expand the educational and analytical utility of the simulator. A compelling conceptual upgrade is the integration of multi-user cooperative training: by leveraging local network or cloud synchronization, multiple trainees with individual HMDs could be placed within the same virtual avalanche scenario. Such an environment would enable rescue teams to practice coordinated search strategies, verbal communication, and triage under realistic time constraints. Furthermore, the framework could be extended to include randomized multiple-burial configurations, allowing advanced users to train transceiver marking (flagging) functions, signal resolution, and complex search tactics.

7. CONCLUSION

Avalanche Rescue VR serves as a highly effective, low-barrier, and data-rich complement to physical field training, advancing alpine safety education. By utilizing immersive virtual reality, the simulator enables trainees to repeat complex, stressful rescue scenarios, and hardwiring procedural schemas. The analysis of 515 tracked runs demonstrates that while trainees excel in physical tool packing, critical planning and mobile safety checks remain a major point of omission. At the same time, spatial tracking proves that trainees successfully acquire complex technical skills like the 'airport approach' search technique. By combining highly engaging immersive practice with scientific diagnostic tracking, Avalanche Rescue VR represents a significant leap forward in saving lives through modern alpine safety education.

8. ACKNOWLEDGEMENTS

The development of Avalanche Rescue VR was funded and directed by the Avalanche Warning Service of the State of Tyrol. The authors express their gratitude to Regional Safety Councillor Astrid Mair for her vision and support.

9. REFERENCES

Hetzenauer, A.-L., 2025. Immersive Alpine Preparedness: Enhancing Avalanche Rescue Training Through Virtual Reality, Master's thesis, Department of Computer Science, University of Innsbruck, Austria.

Lanzanasto, N., Sitar, C., Mair, P., Hetzenauer, A.-L., 2025. Lawinennotfalltraining in Virtual Reality – Erfahrungen mit der App „Notfall Lawine VR“, in: Proceedings of the Avalanche Symposium 2025, Innsbruck, Austria, October 2025, 12-18.

Rauch S, Brugger H, Falk M, et al. Avalanche survival rates in Switzerland, 1981-2020. JAMA Netw Open. 2024;7(9):e2435253. doi:10.1001/jamanetworkopen.2024.35253