TAT VR: a Virtual Reality Simulator for Military Shooting Training

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ABSTRACT

Traditional military shooting training methods have high costs, logistics complexity, spatial-temporal constraints, and safety risk. VR-based simulation can help address these drawbacks while serving as a platform for supplementing current training approaches, providing more convenience, accessibility, and flexibility. This work aims at analyzing the application of virtual reality in the Brazilian Army's pistol shooting training through the TAT VR simulator. This simulator was tested by a sample composed of five Army officers and one Navy officer with practical shooting experience. The results were compared with reference values obtained from related work. The data showed that TAT VR reached the reference values for the two evaluated parameters: sense of presence and effectiveness.

CCS CONCEPTS

• Human-centered computing → Virtual reality; **• Software and its engineering → Virtual worlds training simulations**; **• Applied computing → Military**.

KEYWORDS

Virtual reality, Virtual worlds training simulations, Military

ACM Reference Format:
Romullo Girardi, Adinê Alves Pereira Filho, Gabriel Pinheiro Teodoro, and Jauvane C. de Oliveira. 2022. TAT VR: a Virtual Reality Simulator for Military Shooting Training. In *24th Symposium on Virtual and Augmented Reality (SVR 2022), October 24–27, 2022, Natal, RN, Brazil*. ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3604479.3604504

1 INTRODUCTION

In the military context, shooting is one of the most important individual skills and should be a widely performed practice. For this reason, shooting training is a mandatory activity for all military personnel of the Brazilian Army [19]. This training aims at developing the technical and psychomotor skills for the correct application of shooting fundamentals and techniques [18].

SVR 2022, October 24–27, 2022, Natal, RN, Brazil

ACM ISBN 979-8-4007-0002-6/22/10…$15.00
https://doi.org/10.1145/3604479.3604504

As in other military activities, the traditional training methods have high costs, logistics complexity, and spatial-temporal constraints [27]. VR-based simulation can help address these drawbacks while serving as a platform for supplementing current training approaches, providing more convenience, accessibility, and flexibility [25].

The application of the VR key elements (virtual world, immersion, sensory feedback, and interactivity) offers a valuable experience to the end user [46] and recent studies have proved that computer-simulated environments can effectively help establish the link between theory and practice while providing a safe environment in which to acquire experience [13]. As safety is an important issue in the military training context, Armed Forces have seen an increased interest in using virtual environments for training purposes [50].

In the military shooting training background, it was possible to find sixteen scientific publications ([2], [8], [14], [15], [20], [24], [26], [30], [32], [38], [42], [43], [45], [47], [48], and [51]) in the last five years that address the application of virtual reality in this instructional activity (considering the Scopus and Web of Science (WoS) databases). Although there is this current discussion on the subject, the authors have not yet found any work that evaluates the application of a commercial Head-Mounted Display (HMD) in military pistol shooting training.

To fill this gap in the specialized literature, this work aims at evaluating the application of a commercial HMD (Oculus Quest) in the Brazilian Army's pistol shooting training through the development and testing of the TAT VR simulator.

Based on this proposed objective, the article is structured as follows: Section 2 details the methodology used; Section 3 presents a high-level view of the TAT VR simulator; Section 4 shows the simulator tests results; and Section 5 concludes with the final considerations of the article.

2 METHODOLOGY

To achieve the objective proposed in the Introduction, the work constitutes a study based on quantitative and qualitative approaches [9] to evaluate the development and testing of a VR application in the Brazilian Army's pistol shooting training. To this end, the effort was structured in four phases:

(1) **Bibliographic review:** analysis of related works to understand the state of the art related to the application of VR in military training simulators (Section 3). It is noteworthy that the search scope was expanded from "military shooting

training" to "military training" to obtain a larger sample of articles and a broader view associated with the application of virtual reality in this instructional activity. The bibliographic review was based on the following search strategy:

Databases: Scopus and WoS [41].

Period of time: last five years (from 2017 to 2022).

Search parameters in the Scopus database: TITLE-ABS-KEY((”virtual reality” OR "VR") AND ("military" OR "defense" OR "defence" OR "navy" OR "army" OR "air force") AND ("training" OR "practice" OR "instruction" OR "preparation")) AND PUBYEAR AFT 2016.

Search parameters in the WoS database: TS = ((”virtual reality” OR "VR") AND ("military" OR "defense" OR "defence" OR "navy" OR "army" OR "air force") AND ("training" OR "practice" OR "instruction" OR "preparation")) AND PY = (2022 OR 2021 OR 2020 OR 2019 OR 2018 OR 2017).

(2) **Simulator design:** a high-level view of the TAT VR simulator, describing the target problem, the specified solution, the technologies used, and an overview of the application (Section 4).
(3) **Simulator tests:** TAT VR evaluation through tests with a sample composed of five Army officers and one Navy officer with practical shooting experience (Section 5).
(4) **Simulator validation:** after the presentation of the parameterized results from related work and those obtained by TAT VR, it was performed a comparative analysis to validate the simulator considering two parameters: sense of presence and effectiveness (Section 6).

The four steps of the methodology are summarized in Figure 1.

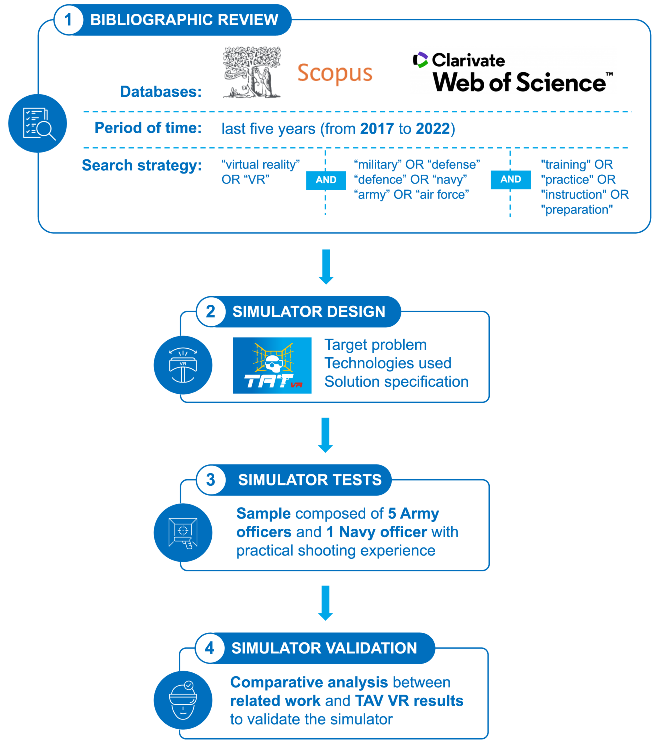

Figure 1: Summary of the methodology used in the research

3 RELATED WORK

This section presents recent works (published in the last five years in Scopus and WoS databases) linked to military training VR simulators.

According to these criteria, the following papers were chosen and analyzed: [1], [2], [3], [4], [5], [6], [7], [8], [10], [11], [12], [14], [15], [17], [20], [21], [22], [24], [26], [28], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [42], [43], [44], [45], [47], [48], [49], and [51].

[1], [12], [14], and [40] presented systematic reviews of the literature that address the use of immersive simulations in training activities, including military ones. [1] discussed the virtual reality applied for enhanced education learning, military training, and sports. [12] showed a review about XR applied in flight simulators. [14] reviewed the use of virtual reality simulators for training programs in the areas of security and defense. [40] investigated the impact of VR technology on 46 immersive gamified simulations with serious purposes.

[2], [3], [4], [5], [6], [7], [8], [10], [11], [15], [17], [20], [21], [22], [24], [26], [28], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [42], [43], [44], [45], [47], [48], [49], and [51] presented and evaluated VR applications for specific military training activities. [2] investigated the efficacy of brain training by using virtual reality and real shooting on the shooting skills of students in a military university. [3] analyzed experiments and survey results of a VR application developed for Pakistani Army military physical training. [4] showed a U.S. Navy VR simulator for training maintenance procedures. [5] presented a VR simulator for Belgian firefighters training. [6] described a study using VR simulation to assess performance in Canadian Navy emergency lifeboat launches. [7] tested the applicability of a virtual reality simulation platform for stress training of first responders in military scenarios. [8] developed a shooting impact detection system for virtual simulations. [10] presented a Thai aircraft recognition training simulator using virtual reality. [11] showed a VR simulator for training the control of military drones. [15] evaluated the influence of emotional aspects on military shooting performance using VR simulations. [17] showed a helicopter visual signaling VR simulation used to optimize Brazilian Navy training. [20] described a virtual reality soldier simulator with body area networks for Taiwanese Army team training. [21] analysed the implementation of virtual reality technology for military training and education in Colombia. [22] presented a VR simulator for Brazilian Army Artillery Observer Training. [24] illustrated U.S. Army design choices for training school teachers, administrators and other staff in a virtual environment in the event of a school shooting. [26] presented simulating laser dazzling using augmented and virtual reality. [28] showed a Chinese field operation rescue simulation system based on virtual reality. [30] detailed a multiplayer shooting game-based simulation for defense training. [31] evaluated technology acceptance and usability of a virtual reality intervention for military members and veterans with post-traumatic stress disorder. [32] discussed educational approaches of simulation

learning in a virtual 3D environment close to reality. [33] described the design and usability evaluation of a mixed reality prototype to simulate the role of a U.S. Army tank platoon leader. [34] developed a modular stress management VR platform for Australian pilots training. [35] presented an immersive VR platform for training Italian CBRN (Chemical, Biological, Radiological, and Nuclear) operators. [36] described a real-time tool for monitoring soldiers' stress in a dynamic military virtual reality scenario. [37] showed an immersive first-person shooter serious game for military training. [38] designed and evaluated a SteamVR tracker for training applications. [39] discussed a VR-based shooting training simulator with focus on combat stress management. [42] integrated biocybernetic adaptation in VR target shooting training. [43] analysed the impact of fire arms training in a virtual reality environment. [44] analyzed the use of VR in the U.S. Air Force initial flight training. [45] evaluated postural instability and seasickness in a motion-based shooting simulation. [47] discussed the design and realization of a shooting training system for police force. [48] showed an ad-hoc study on soldiers calibration procedure in virtual reality. [49] discussed landmine detection training simulation using virtual reality technology. [51] presented an haptically enabled simulation system for firearm shooting training.

In addition to the works related to VR simulators for military training, it was sought a specification for measuring the sense of presence experienced in a virtual environment. In this context, the specification IPQ (Igroup Presence Questionnaire) was used as a reference. The IPQ questionnaire is a tool to objectively evaluate the sense of presence in a virtual experience from the assignment of values, on a scale from 0 to 6, for 14 items: 1 general item (G1), 5 items for Spatial Presence (SP), 4 items for Involvement (INV), and 4 items for Realism (REAL). The G1 item evaluates the user´s general presence perception. The SP items evaluate the sense of being physically present in the virtual environment. The INV items evaluate the attention devoted to the virtual environment and the involvement experienced. The REAL items evaluate the subjective experience of realism in the virtual environment. Along with the questionnaire, the IPQ specification provides data from hundreds of papers that have used this measurement tool to evaluate the sense of presence in virtual experiences [29].

3.1 Related work results parameterization

After the presentation of papers that use virtual reality in military training, it is necessary to parameterize the data obtained in order to synthesize an objective evaluation of the exposed content. The parameters considered are sense of presence and effectiveness.

Firstly, regarding the sense of presence, the data provided by the IPQ (Igroup Presence Questionnaire) specification was used as a reference. In its latest available version, the IPQ database provides 619 case studies. Considering the 18 case studies that used VR applications with first person perspective, stereoscopic HMD, and stereo audio, the reference values for the IPQ specification parameters are presented in Table 1. As explained in Section 3, the IPQ specification parameters are: General Presence Perception (G1), Spatial Presence (SP), Involvement (INV), and Realism (REAL).

Secondly, considering that effectiveness is the degree to which something is successful in producing a desired result [16], two types of indicators were considered: subjective and objective. The subjective indicators are those raised through the user's subjective perception when responding to a questionnaire. Within the scope of related work, most participants, when asked, presented a positive perception regarding the effectiveness of the VR training simulations. About the objective indicators, these are based on the data provided by the simulation. Considering the papers analyzed, the participants presented, on average, during the simulations, time reduction and/or performance improvement associated with the execution of the training task. Based on the results obtained by related work and as a way to parameterize the effectiveness evaluation in a virtual reality simulation, these following reference values were specified:

- **SUBJECTIVE EFFECTIVENESS**
  - Absolute effectiveness: most participants should evaluate the training tool as effective.
  - Relative effectiveness: if there is a group that has experimented with a simulator that does not use virtual reality for the training in question, most participants in this group should evaluate the training tool with VR more effective than the tool without VR.
- **OBJECTIVE EFFECTIVENESS**
  - During the simulations, there should be a decrease in the average time and/or an increase in the average performance throughout the execution of the training task.

Table 2 synthesizes the reference values for effectiveness evaluation.

Table 1: Reference values for sense of presence based on the IPQ database (case studies with first person perspective, stereoscopic HMD, and stereo audio)

IPQ Parameters	Reference Values (IPQ Database)	
	Average	***Standard Deviation***
G1	3.000	1.969
SP	3.178	1.673
INV	2.986	0.941
REAL	2.167	1.022

Table 2: Reference values for effectiveness based on related work

Effectiveness Parameters	Reference Values (Related Work)
Subjective Absolute Effectiveness	Should be perceived by most participants
Subjective Relative Effectiveness	Should be perceived by most participants who have already used a similar tool without VR
Objective Effectiveness	In the training task execution throughout the simulations, there should be a decrease in the average time and/or an increase in the average performance

4 TAT VR SIMULATOR

After analyzing papers related to the application of VR in military training, this section details the simulator developed and tested in this work, which is called TAT VR.

In the context of the Brazilian Army, shooting training is a mandatory practice for the military. Every year all officers must take the Shooting Aptitude Test (TAT). The TAT consists of firing fifteen rounds with a 9mm pistol at a target 25 meters away. The target follows the A2 pattern (shown in Fig 2). The shooter's rating is based on the number of hits to the target's silhouette [19].

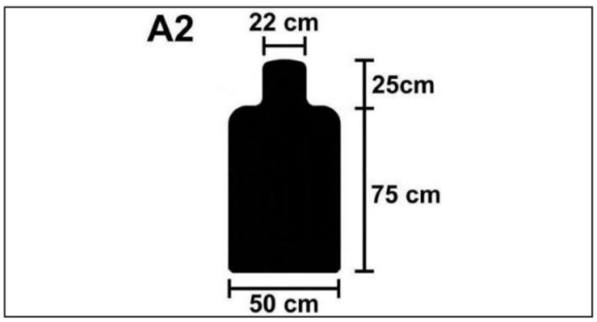

Figure 2: A2 target specification

To simulate the test, TAT VR provides a 6-DOF VR experience that allows the shooter to move around the shooting range, handle the pistol and take the shots. Figure 3 shows, on the left, one of the sample elements performing the test with the simulator. In the upper right corner, the TAT VR home menu. In the lower right, the user in the virtual shooting range.

Figure 3: TAT VR overview

Table 3 presents the technologies used in the implementation of the TAT VR simulator.

Table 3: Technologies used in the simulator implementation

Game Engine	Unity
Language	C#
HMD	Oculus Quest
Virtual Reality Framework	Functionalities related to data persistence and HMD interaction was supported by the IME VR Framework [23]

5 TESTS

To perform the tests with the TAT VR simulator, it was used a sample composed of five Army officers and one Navy officer. All elements of the sample have practical shooting experience.

Initially, each participant went through a preparation phase for the interpupillary distance (IPD) calibration and adaptation to the virtual world and controllers of the immersive experience. The Oculus Quest HMD has an IPD range from 58 to 72 mm.

After preparation, three repetitions of the test were performed for each participant. Test data were collected through 2 approaches: a subjective and an objective one. Figure 4 summarizes the data collection used during the tests.

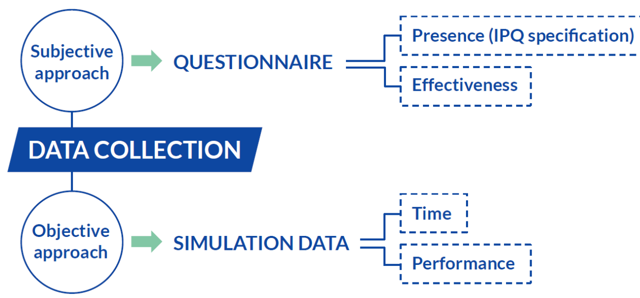

Figure 4: Test data collection

Firstly, the subjective approach was based on the application of a questionnaire in order to verify the user's subjective perception about the simulator. This questionnaire consisted of 2 parts: one related to the sense of presence in the virtual environment and the other related to the simulator effectiveness. The presence part consisted of the 14 questions specified by the IPQ questionnaire [29]. The effectiveness part consisted of 2 questions:

(1) (Absolute effectiveness) Do you think that the TAT VR simulator is effective for pistol shooting training (Likert scale from 1 to 5)?
(2) (Relative Effectiveness) If you have ever tried any pistol shooting training game or simulator that does not use VR (Virtual Reality), do you think that the TAT VR simulator is less, equal or more effective than the tool without VR (Less/Equal/More)?

Secondly, the objective approach was based on the data provided by the simulation. The simulation data were collected in terms of time and performance. Regarding performance measurement, the number of hits on the target silhouette and the dispersion were considered. The dispersion metric was calculated from the standard deviations associated with the shooter's impacts on the target considering the x and y axes.

$$\sigma = \sqrt{\sigma_x^2 + \sigma_y^2}$$

$$\sigma_x = \sqrt{\sum_{i=1}^{N} \frac{(x_i - \eta_x)^2}{N}}$$

$$\sigma_y = \sqrt{\sum_{i=1}^{N} \frac{(y_i - \eta_y)^2}{N}}$$

η_x and η_y represent the respective average positions of the impacts on the target, N is the total number of shots, x_i and y_i are the distances of the i-th shots on the respective axes.

After the TAT VR tests, the data were collected according to the parameters used for the analysis of related work. As seen in Section 3.1, these parameters are: sense of presence, subjective absolute effectiveness, subjective relative effectiveness, objective effectiveness in terms of time and objective effectiveness in terms of performance.

5.1 Sense of Presence

After obtaining the data of the users through the questionnaire, the IPQ parameters results were calculated and are presented in Table 4.

Table 4: Sense of presence in TAT VR (IPQ evaluation)

IPQ Parameters	TAT VR Results	
	Average	*Standard Deviation*
G1	5.83	0.37
SP	5.40	0.31
INV	5.29	0.68
REAL	5.12	0.88

5.2 Subjective absolute effectiveness

Among the six users of the TAT VR tests sample, all evaluated the simulator as an effective tool for pistol shooting training. On a Likert scale (from 1 to 5), all participants scored values greater than or equal to 4, with an average of 4.33. Thus, the subjective absolute effectiveness was 83.25%.

5.3 Subjective relative effectiveness

Among the six users of the TAT VR tests sample, 3 had already used some non-VR tool for pistol shooting training. As shown in Figure 5, in this group of 3 people, 1 evaluated TAT VR as effective as the tool without VR (33.3%) and 2 evaluated TAT VR more effective than the tool without VR (66.7%). Thus, the subjective relative effectiveness was 66.7%.

5.4 Objective effectiveness in terms of time

After analyzing the simulation data of the six users who were the sample for the TAT VR tests, it was verified, as shown in Figure 6, that the average time for the shooter to perform the test decreased by approximately 42.8% (from 264 to 151 seconds).

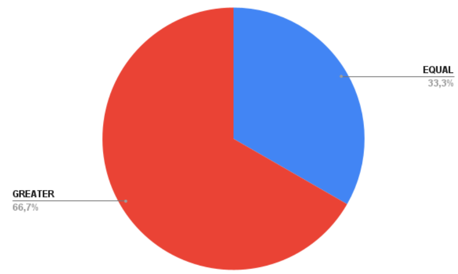

Figure 5: TAT VR effectiveness over similar simulators that do not use VR

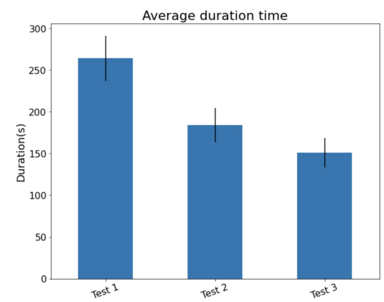

Figure 6: Average time of tests (in seconds)

5.5 Objective effectiveness in terms of performance

After analyzing the simulation data of the six users who were the sample for the TAT VR tests, it was verified, as shown in Figure 7, that the average shooter performance in terms of hits increased by approximately 32.7% (from 10.17 to 13.50). Regarding the average dispersion of impacts, as shown in Figure 8, there was a decrease of approximately 22.3% (from 0.695 to 0.540).

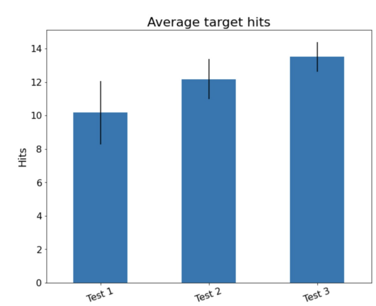

Figure 7: Average performance in tests (number of hits)

6 DISCUSSIONS & CONCLUSION

After the presentation of the parameterized results from related work (Section 3.1) and those obtained by TAT VR (Section 5), it was possible to perform a comparative analysis based on the two parameters considered: sense of presence and effectiveness.

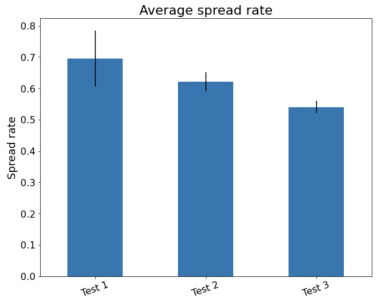

Figure 8: Average performance in tests (dispersion)

Regarding the sense of presence, as shown in Table 5, TAT VR average values were higher than the average reference values for all IPQ specification parameters, namely, General Presence Perception (G1), Spatial Presence (SP), Involvement (INV), and Realism (REAL). In addition, the IPQ parameters standard deviation values of the TAT VR simulator were lower than those obtained from the IPQ database case studies. As the IPQ database gathers results from different simulators, their values are more dispersed than the values obtained by TAT VR.

Table 5: Related work reference values X TAT VR results (Presence)

IPQ Parameters	Reference Values		TAT VR Results	
	Average	*Std Dev*	*Average*	*Std Dev*
G1	3.000	1.969	5.830	0.370
SP	3.178	1.673	5.400	0.310
INV	2.986	0.941	5.290	0.680
REAL	2.167	1.022	5.120	0.880

About effectiveness, reference values were divided into two groups: subjective effectiveness (linked to indicators raised through subjective user perception when responding to a questionnaire) and objective effectiveness (linked to indicators obtained from the data provided by simulation). The reference values related to subjective effectiveness specified that most participants should report absolute and, when possible, relative effectiveness of the simulator. The reference values related to objective effectiveness determined that, during the simulations, the participants should present a decrease in the average time and/or an increase in the average performance associated with the training activity execution. The TAT VR simulator presented absolute subjective effectiveness of 83.25%, relative subjective effectiveness of 66.7% and, throughout the simulations, an average time decrease of approximately 42.8% (from 264 to 151 seconds), and an average performance increase in terms of hits and dispersion. The average shooter performance in terms of hits increased by approximately 32.7% (from 10.17 to 13.50) and the average dispersion of impacts decreased by approximately 22.3% (from 0.695 to 0.540). As shown in Table 6, TAT VR reached all reference values related to the effectiveness parameters.

This comparative analysis suggests that the TAT VR simulator reached the reference values linked to related work of Section 3.

Table 6: Related work reference values X TAT VR results (Effectiveness)

Effectiveness Parameters	Reference Values (Related Work)	TAT VR Results
Subjective Absolute Effectiveness	Should be performed by most participants	83.25%
Subjective Relative Effectiveness	Should be performed by most participants (when possible)	66.7%
Objective Effectiveness	$\Delta time_{av} < 0$ and/or $\Delta performance_{av} > 0$	Δt = -42.8% Δp = 32.7% (hits) Δp = -22.3% (disp)

Thus, based on the VR military training simulators contained in the scope of this research, the application of virtual reality in the Brazilian Army's pistol shooting training obtained a satisfactory result in the two evaluated parameters: sense of presence and effectiveness.

Considering the benefits related to the development of TAT VR, it is possible to point out the following aspects:

- The use of VR allowed savings of financial and material resources, reduction of safety risk, greater repeatability in training; and more detailed performance control (dispersion calculation in addition to the number of hits).
- As it is based on a commercial HMD (Oculus Quest), the simulator has high scalability, reliability, availability, and maintainability.

As limitations, it is worth mentioning that:

- Due to the fact that TAT VR uses the Oculus Quest controller, the simulator has low realism regarding the weight and recoil of the weapon.
- Also regarding the limitations related to the use of a commercial HMD, aiming accuracy and precision are limited to the technical characteristics of the Oculus Quest.
- The bibliometric study conducted during the literature review was restricted to works related to the military field.
- The sample used in the validation of the simulator was small (six Brazilian officers) and no comparison was made with real-life shooting data.

About future work, the following possibilities can be indicated:

- Replacement of the Oculus Quest controller with a real sensed pistol and addition of a recoil mechanism (e.g., a compressed air system) to increase simulation realism.
- Usage of outside lighthouses for tracking to improve aiming accuracy and precision.
- VR stereoscopic vision and space compression are factors that can affect aiming accuracy and precision. Since objects seem to appear closer in VR then in real life, an specific study could assess how aiming can be influenced by misleading perception of distance.
- The analysis of the application of VR in shooting training can be improved through a more robust systematic review of the literature, expanding the scope to include studies not only limited to the military field.

- Conducting a more rigorous validation of the simulator through the use of a larger sample and comparison with real-life shooting data.

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