POLITECNICO DI TORINO

MASTER's Degree in COMPUTER ENGINEERING

MASTER's Degree Thesis

Virtual equine respiratory endoscopy system for educational applications

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APRIL 2023

Alla mia famiglia e ai miei amici

Abstract

Training in virtual reality (VR) is a highly immersive and interactive learning method which enables learners to engage in simulated real-world scenarios. This approach provides a unique opportunity for learners to practice and develop critical skills in a safe and controlled environment, without the risk of causing harm to themselves or others. By offering a safe space to learn, trainees can experiment with different scenarios, make mistakes, and refine their skills in a risk-free environment.

VR training has been shown to be a highly effective learning method across a wide range of fields, including medical and veterinary education. Compared to traditional classroom or e-learning methods, VR training is more engaging, efficient, and faster. This approach not only enhances learners' retention of knowledge and skills but also helps them to gain confidence in applying them in real-life situations.

This thesis is focused on the development and implementation of a software program designed to simulate an equine upper airway endoscopy procedure in collaboration with the Department of Veterinary Science of the University of Turin. The primary goal of this project is to create a virtual learning tool for educational purposes that will replace, either entirely or in part, the traditional training process for this procedure. By doing so, it will overcome some of the limitations related to the limited availability of patients and the risks associated with performing this procedure on live animals. The aim is to integrate the work that has been already done in a previous thesis activity, enhancing its functionality, with a mechanism for simulating certain diseases and for monitoring and evaluating the student, who must be able to follow the analysis procedure correctly.

The validity and efficiency of this tool were evaluated by collecting and analyzing the results of experiments carried out by students who have tried out the application. These experiments provided valuable insights into the effectiveness of the tool and its potential to enhance the learning experience for veterinary students. The results of these experiments will serve as an important reference for future research and development in the field of veterinary medicine and education.

Table of Contents

Acronyms

VR
: Virtual reality

RLN
: Recurrent Laryngeal Neuropathy

DDSP
: Dorsal Displacement of Soft Palate

PLH
: Pharyngeal Lymphoid Hyperplasia

ECA
: External carotid artery

MA
: Maxillary artery

ICA
: Internal carotid artery

SUS
: System Usability Scale

UEQ
: User Experience Questionnaire

IMMS
: Instructional Materials Motivation Survey

Chapter 1

Introduction

1.1 Thesis objective

Virtual reality (VR) has gained much popularity in recent years, becoming an increasingly powerful and significant tool in education and training. Because of its ability to create safe and controlled simulated environments, VR has emerged as an effective method for learning and practice in various disciplines.

This thesis, developed at the VR@POLITO lab of Politecnico di Torino with the support of Prof. Michela Bullone from the Department of Veterinary Science, focuses on the application of VR in veterinary education, specifically nasal endoscopy in horses. Endoscopy is a noninvasive medical procedure that allows the examination of the internal cavities of animals through the use of an endoscope. In the veterinary setting, endoscopy is a key diagnostic tool for identifying and monitoring various diseases.

The goal of this thesis is to assess the potential advantages and disadvantages of a virtual learning tool, designed for a VR platform, intended to enhance student training in endoscopic procedures. By addressing constraints associated with the limited availability of horses, this tool aims to minimize risks to both the animals and the students. Additionally, the thesis aims to provide as realistic and immersive an experience as possible.
To achieve this goal, a VR application simulating an endoscopic examination on a horse was developed using the Unity development platform and the Oculus Quest 2 VR headset. The project builds on the work done in a previous thesis, which made the 3D reconstruction of a horse's nose from a computed tomography (CT) scan and integrated it into a Unity project to enable interaction.

The current thesis work aims to extend the previous work by simulating a complete endoscopic examination check. During the simulation, users will have to identify the various conditions implemented in the virtual model. In addition, a mechanism will be introduced to evaluate whether the user correctly detected the various problems encountered during the virtual experience.

Once the application was completed, an experiment was organized with a group of veterinary students, recruited by Professor Bullone. The purpose of this experiment was to evaluate the effectiveness of teaching through VR in terms of learning and skill acquisition. To analyze the results obtained, all available data related to the learning and performance of the students involved in the experiment were collected and recorded. These data will be analyzed in detail in the following chapters of this thesis in order to draw conclusions about the impact of VR in the education process of veterinary students and to evaluate whether this technology can indeed be a valuable complementary or alternative teaching tool to traditional methods.

1.2 Extending previous work

This thesis work represents an extension of a previous project carried out in collaboration with Professor Bullone at the University of Turin. The main goal of the project was to develop an accurate model of the equine upper respiratory system, an extremely complex task that required the use of advanced techniques, such as computed tomography (CT).
In the previous work, a virtual environment that would reproduce the room in which endoscopy is performed at the University of Turin has been recreated. In particular, that involved the horse's body, including the animation system, the monitor, and the various devices used in endoscopy, plus the body of the endoscope itself. Next, these models were imported into the Unity engine to create a realistic simulation environment that could be virtually explored through the Oculus Quest 2 VR headset. In addition, a system for inserting the tip of the probe into the horse's nostril and for moving it inside the nasal cavities has been implemented.

1.3 Approach and Implementations

This thesis aims to refine a previously developed simulation model with the goal of improving the experience and learning of students in the field of veterinary medicine. The initial model had some limitations, mainly due to the low resolution of images obtained by CT scan. Therefore, the first step was to rework the existing model, refining the anatomical structures and increasing textures quality. In addition, the virtual room in which the simulation takes place was redesigned, improving the lighting, textures, and interactions with the horse. Among these improvements, the nasal insertion of the probe and the movement of the cable inside the nose has been optimized, making navigation and exploration smoother and more realistic. To further enrich the simulation, a set of diseases and conditions, provided by Professor Bullone, that may afflict the animal has been implemented. The student is required to correctly identify and report these diseases during the immersive experience. A combinatorial model was created to generate these diseases, allowing the teacher to select the conditions for the student to recognize. In order to further enhance the teaching experience, a tutorial was introduced to guide users struggling with the application for the first time, and an evaluation system for students carrying out the experience has been designed. In the following chapters, all the aspects mentioned will be described and analyzed in detail, highlighting the improvements made to the previous work and the impact of these changes on student learning in the field of veterinary medicine.

Chapter 2

State of the art

2.1 Virtual Reality in education

One of the fields where VR has been most successful is education, allowing students to have highly immersive experiences, engaging and inspiring them in a unique and powerful way.
VR applications promote learning relying on the concept of constructivism [2], which asserts that knowledge acquisition is an active effort in which individuals learn from their experiences that create with their surroundings.
Although low-interactive virtual environments do not allow users to learn through practical experience, they are powered by the integration of cognitive helps. These assists facilitate the ability to imagine a problem in three dimensions, reducing cognitive load [18].

2.2 Virtual reality for educational training

VR has offered significant support in the medical field: while the traditional method of having a teacher as a tutor remains excellent, it may pose risks to patients [15]. Additionally, VR has proven to be an important tool for enhancing teaching methods and achieving better outcomes, particularly in specific and rare cases. One of the key aspects of VR in this context is simulation, which involves the use of computer-generated environments to mimic real-world scenarios into a virtual world for training purposes. Simulation introduces new tailored training experiences in a totally controlled environment that can be standardized, as well as the opportunity to benefit from self-directed learning that focuses on the deficiencies of the single user.
Training with VR extends to a new range of skills that may not be measurable through traditional methods. For example, a simulation has the ability to track the

movement of surgical instruments, and measure instability or errant movements through automatic and immediate feedback. Simulation provides a much more appealing solution that allows students comparing and reviewing their performance. [15] [16].
In addition to educational benefits, VR also offer advantages on the economic side, for instance by creating a virtual operating room that allows surgeons to practice from anywhere or even mitigating the cost of travel, corpses, and shipping of large medical or robotic devices. VR can open new channels of communication with mentors, allowing more interactive and guided interaction, and join international conventions in immersive mode from anywhere.
VR is not a panacea, so the merits and demerits involving it and some well-known current applications will be analyzed below.

2.2.1 Advantages of VR in education

Access limited resources

As mentioned earlier, VR is very useful because it enables activities not easily achievable in any other way, but also because it provides almost unlimited resources, from equipment to labs or whatever.

Remote learning

VR has the potential to be used in distance learning [11]. Distance learning allows students to access materials and resources from leading universities around the world, regardless of their location, and studies have found that students prefer this type of solution. An example is the one simulating oral emergency medicine exercises for students [7]. The authors designed a simulated exam room that could be accessed remotely via the Internet, in which students assumed the role of the doctor and the examiner supervised the patient. Seventy-three percent of the 27 medical students involved in the experiment considered it a more realistic setting than the traditional exam. In addition, the traditional method can also involve time spent traveling, which can also be environmentally bad since many business trips are often planned via airplane, as well as a cost. Immersive learning, on the other hand, allows training to be conducted directly in the office or at home, which has consequent benefits [21]. Moreover, VR headsets are becoming cheaper and cheaper, and one is not limited among the few choices available as in the past.

Highly engaging training

Higher engagement rates typically lead to higher retention rates and recall. If learners pay attention to what they're learning, they'll remember it more effectively.

Memory retention after a VR experience is higher than the one obtained by studying video or text materials. A study explains how memory is made stronger with increased multi-sensory and emotional input [16]. This type of education also has a strong impact on students' motivation, defined as their desire or incentive to participate in the session. Students are typically more motivated by 3D graphical applications than 2D.

Figure 2.1: Virtual laboratory environment created for the VEMA application [12]

An example of software that aims to demonstrate how VR can be implemented in engineering to improve safety and efficiency in the use of electrical equipment, is the Virtual Electric Manual (VEMA) [12]. VEMA should not replace the traditional teaching method, but should be a supportive tool to facilitate understanding and be more motivated in studying the matter.

Experimental learning

Learners who take VR courses can be trained up to four times faster than conventional classroom training [34]. As can be seen in the plot in Figure 2.2 made available by PwC, the use of VR makes it possible to reduce the time needed to learn concepts that would take two hours in a classroom to just 30 minutes. Even taking into account the additional time required for newcomers to become familiar with the use of the VR headset, learners in VR complete training three times faster than their classroom counterparts. These statistics does not take into account the additional time required to reach the location of the training, which makes VR even more beneficial from the perspective of time spent as discussed previously.

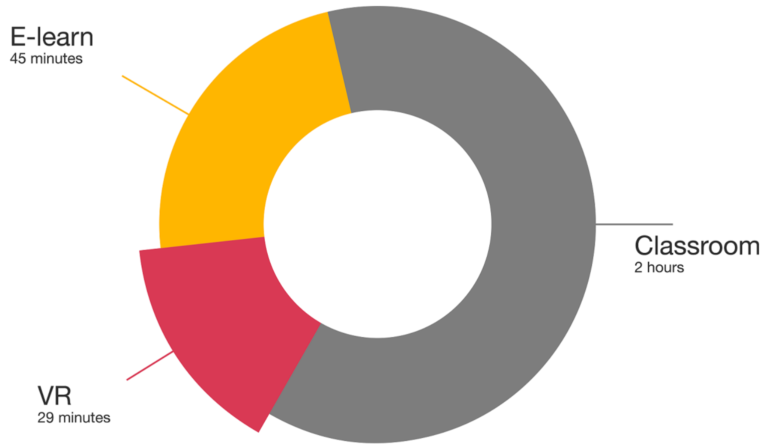

Figure 2.2: Plot representing the differences in time between traditional teaching and through VR [34]

Also, again in terms of motivation, today's students often demonstrate impatience, lack of concentration and a sense of overwhelm. A large number of them are unable to watch an entire video, with smartphones being a major source of interruption and distraction. Virtual reality experience offers a significant reduction in distractions. Wearing a VR headset, individuals are fully engaged in immersive simulations and activities that capture their vision and concentration.

Collaboration

Again, related to the topic of motivation and concentration, a very important element that can be fully exploited with VR is the cooperation among students facilitated by simulation.

Numerous studies have shown that education in the medical field has some shortcomings in both the development and evaluation of not only individual technical skills, but also interpersonal skills, such as teamwork and leadership, which are particularly valued in procedures performed by teams [14]. Medicine has benefited significantly from collaborative virtual environments (CVEs), which are particularly useful for surgical training applications. CVEs are systems that allow multiple users to interact with each other in real-time and facilitate the practice of medical procedures by users who can share experiences with remote tutors or other students. One example is SIMCEC (Collaborative Simulator for Surgical Team Training) [45], which has as its main objective to assist in the process of training and evaluating students at the undergraduate and technical level of health courses regarding the fundamental aspects of surgical procedures. Basic surgical techniques and concepts are discussed, such as patient X-ray verification, selection of anesthetic drugs and surgical instruments, incision approaches in mandibular fractures, and more.

Figure 2.3: SIMCEC collaborative simulation for surgical team training [45]

Automated feedback

Once the simulations are completed, participants can receive a virtual report and view automatic evaluations of their performance. This review is critical to the training outcomes in any given simulation. In VR, feedback can address both technical and non-technical skills demonstrated in the test versus best practices. This allows students to examine their performance more closely and offers the possibility of blended learning. It also promotes peer learning, as participants can exchange feedback with their peers and mentors, stimulating discussions on specific learning objectives.

2.2.2 Problems with VR in education

Although the benefits of VR simulation are undeniable, it is essential to recognize that is not the best possible solution. Rather, VR simulation serves as a valuable tool designed to achieve specific learning goals [17]. As such, it is critical to implement this technology thoughtfully and integrate it within an educational institution's teaching methodologies. This integration will ensure that VR simulation is used effectively and efficiently, maximizing its potential to enhance the student learning experience.

Cost

Over the past decade, technology has become increasingly expensive. According to [35], integrating VR into all K-12 schools in the United States would involve spending billions of dollars. Even if each district purchased its own products, the individual cost could still range from hundreds of thousands to millions of dollars, depending on the size of the district. It is fair to wonder if the investment is worthwhile or not, but one thing is clear, because of the high costs, only the wealthiest districts could afford it. Under-endowed districts, which serve mainly low-income students, would not be able to purchase virtual reality devices, leading to inequity and disparities in education. In addition to the purchase costs, training and maintenance costs must also be included, which are certainly not indifferent

Training

The implementation of new digital technologies in schools often results in a significant amount of overhead in terms of the time required to train educators. When introducing innovative tools or platforms into educational settings, it is generally necessary to organize dedicated training sessions for teachers and instructors [1] [13]. This is closely related to the financial aspect of this problem, as institutions are likely to have to remunerate teaching professionals for their participation in these training sessions.

Input problems

Virtual reality is not a suitable solution for all possible educational scenarios. In some cases, it may not be the most efficient method to facilitate learning. For example teaching abdominal palpation does not require a complex immersive experience; instead, an accurate physical representation of an abdomen would be sufficient. Similarly, VR may not be the optimal choice for training in specific tasks or procedures, such as cannulation or numerous other practical skills. In these situations, traditional hands-on training methods or physical simulations might prove more advantageous and efficient in terms of teaching and practicing essential techniques [17]. Consequently, it is critical that educators and institutions carefully evaluate the appropriateness of VR technology for each specific learning objective and determine whether its application will truly improve the educational experience or simply add unnecessary complexity. An example is the software developed for a VR system that aims to simulate oral medical emergency examinations in a virtual setting [7]. Although most students expressed a preference for the VR system over conventional methods, some also expressed concerns that the simulation did not accurately reflect their practical experiences. As a result, they felt that the VR system offered only limited benefits to improve their learning process.

Insufficient realism

Virtual characters, controlled by artificial intelligence (AI), are not yet suitable for some objectives, such as communicating bad news. Currently, humans outperform virtual patients in the complexities of language and facial expressions [17]. On the other hand, excessive realism may not necessarily help the student, who may become distracted and mistakenly focus on elements that are not important to the lesson [3].

Lack of engagement

Teaching staff may be difficult to engage to adopt VR as an educational tool. These more experienced professionals may perceive VR as merely a form of entertainment or game, rather than recognizing its potential to significantly enhance the learning experience [17].

Less personal interaction

One disadvantage of virtual learning is the reduction of self-involvement, which affects both interactions with teachers and with other students. In general, it tends to be a solitary activity, and any socialization that occurs is mainly limited to discussions related to course material [24].

2.2.3 Examples of educational applications

In order to provide a comprehensive analysis of the use of VR in medical education, three representative examples have been selected based on specific criteria. The three VR programs have a common link in their application in the field of medical education. All of them are designed to help students and professionals acquire important skills and knowledge through the simulation of medical and laboratory procedures.

Johnson & Johnson Institute & Osso VR: Enhancing surgical training

The traditional approach to training surgeons has remained relatively unchanged over time, despite significant advances in technology. VR has emerged as a key component in contemporary surgical training. In 2017, Johnson & Johnson initiated the use of VR simulations to teach surgeons the implantation of orthopedic devices, a concept further developed and expanded by Osso VR methods [22]. This immersive learning environment allows surgeons to practice operations in a realistic environment without putting patients in danger, leading to reduced errors and increased efficiency and self-confidence.

Figure 2.4: OSSOvr surgeon training application [37]

The results are promising: students who used Osso VR outperformed those who relied on traditional learning tools by 233 percent, and completed 252 percent more steps than their colleagues using passive training methods [33].

GE Healthcare & Immerse: Transforming radiography training

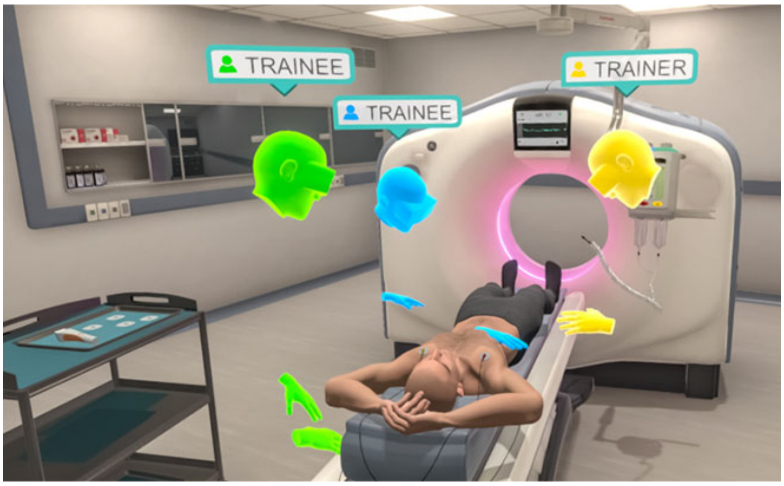

Figure 2.5: Radiography training in a virtual environment [22]

Radiographers to refine their skills have always had to rely on real CT scanners, which were expensive and not easily available. This limitation convinced GE Healthcare to explore the potential of using virtual reality as a training tool for their radiographers. The main goal is to spread virtual training as widely as possible, allowing them to practice various procedures more easily [32]. To deal with this demand, a VR experience was developed that simulated the many steps radiographers must follow during real procedures while operating CT machines.

The observed results have been very satisfactory and include faster and even more frequent training, increasing the availability of scanners when needed as they are not used by students, and the ability to provide real-time feedback during training. It is also an easily scalable system. The combination of these and other advantages as well led one senior in the department to go off the deep end, saying that VR training adds great value because of being able to experience a CCTA (Coronary angiogram) setup without holding up the room or patient list [22].

NHS & Make Real: Blood identification

Another type of application is one dedicated to blood type identification, a particularly critical operation in which it is strongly necessary that no mistakes are made, because they can be lethal.

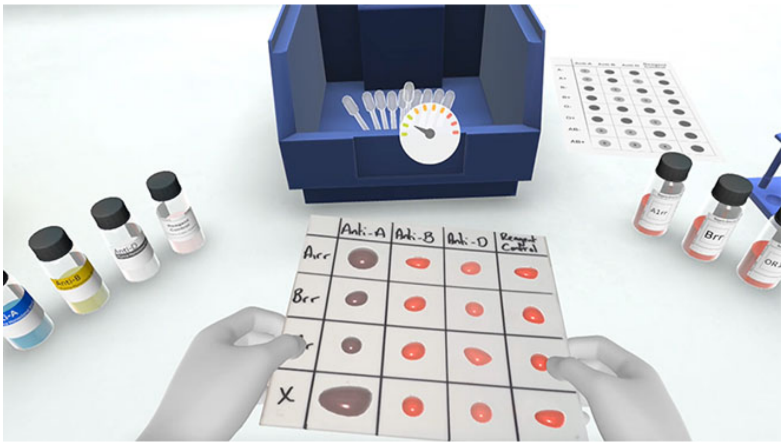

Figure 2.6: Different blood types ready for mixing demonstration [22]

The main purpose of the application is to demonstrate how important it actually is to choose the correct type of blood by showing how quickly blood clots form when different types are mixed together [22]. The application was developed in 2021, using the Oculus Quest as the headset, and plans soon to publish full case studies [36].

2.2.4 VR for veterinary simulations

Experts in the veterinary field and surgeons agree that recent graduates should possess a wide range of surgical skills and apply them with minimal supervision [10].

The use of VR technology in teaching surgery supports the 3Rs principle [28], by providing an alternative method to live animal training, reducing the number of animals needed for training, and refining the process to reduce animal suffering and improve welfare. Many veterinary students preparing to perform their first surgery on a live animal feel negative emotions such as nerves, fear, or stress. Such feelings often arise from a combination of low self-esteem and a strong desire to be adequately prepared [8]. In the following section, four applications within the veterinary field focusing on student training will be presented. These examples encompass a diverse range of educational scenarios, including both livestock management and surgical skill development. This comprehensive analysis aims to demonstrate the versatility and effectiveness of VR as an innovative learning tool in veterinary education.

Canine ovariohysterectomy surgery

The experiment considers two groups of students to which the first group is provided with different types of 2D multimedia materials (Figure 2.7), such as videos, slides, etc. while the second group also has the opportunity to use a VR headset equipped with SimCEC application [45] that allows them to observe pre-recorded surgical procedures. Students were not required to use such a tool, but they were provided with the opportunity to make access to these resources.

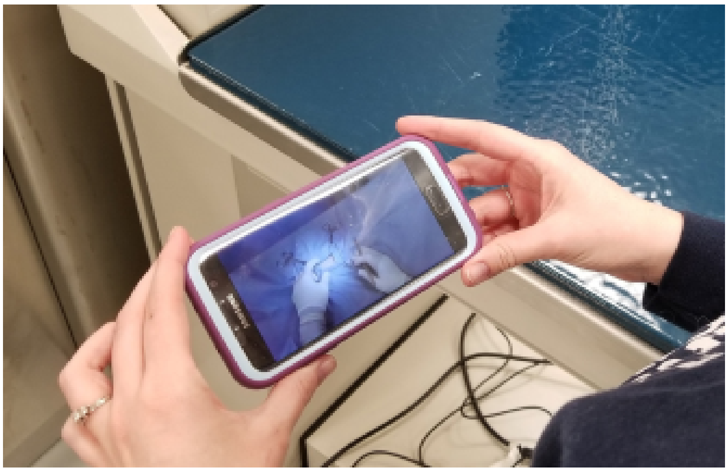

Figure 2.7: Control group Veterinary student studying the procedure via a smartphone video [45].

Regarding the results, 83% (24) students referred that they used the virtual application and that it was useful for their learning and practice. However, there was no difference between the VR and control groups both from the perspective of rubric scores and considering the preparation time to perform surgery.

Virtual animal holding gamifed simulator (ViSi)

ViSi [19] is a training course that consists of a succession of two virtual learning environments as if they were two levels of a video game. The first one consists of an operation preparation room, where the students have to deal with protections (PPE) and select the animal. If all cautions have been taken correctly, then they can move to the next level, which consists of the experiment room, to operate the animal. Here the students begin the actual test, learning to distinguish the sex of the animal based on external features and the various methods of injection. The clues are given through photographs or other elements, and then he must know how to correctly replicate the operation on the model. The VR technology, alongside

Figure 2.8: Injection method illustration to lead the user [19].

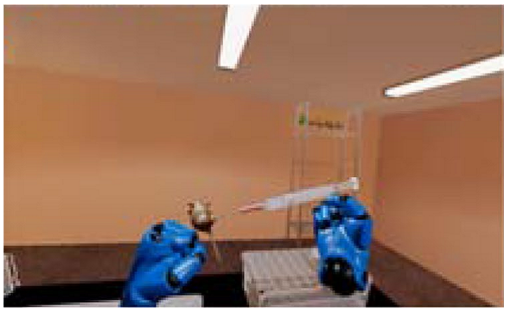

Figure 2.9: User repeating the procedure just seen [19].

traditional teaching methods, received positive feedback. Students appreciated being able to relate to researchers handling animals in the lab and applying the 3R principles. However, some of them experienced difficulty concentrating and adjusting to the VR simulation due to cybersickness. Reducing the simulation time and advancing VR hardware could address these issues.

VR cattle handling experience

This kind of experience requires students to move cattle between fences using the animal management techniques learned in class. To move cattle there is a particular technique that one needs to be aware of, which is walking behind but not getting too close and staying in their blind spot.

Figure 2.10: Animal cattling simulation in virtual reality [31].

Animal science student Bobby Lewis Baida said that being in VR is a lot safer to get to know what the wrong spot is and in this scenario obviously the user can't get injured so it's good practice [31]. This VR application has been so successful that the university that developed it has also invested $100,000 in a project regarding agriculture.

RoVR

Orthomed, a member of the Infiniti Medical family, has announced a partnership with Osso VR, which as seen previously is one of the spokesmen for virtual applications applied in surgery. The first module in RoVR [40] will focus on canine cruciate ligament repair surgery, a standard method for treating torn knee muscles in dogs, enabling them to regain movement [20].

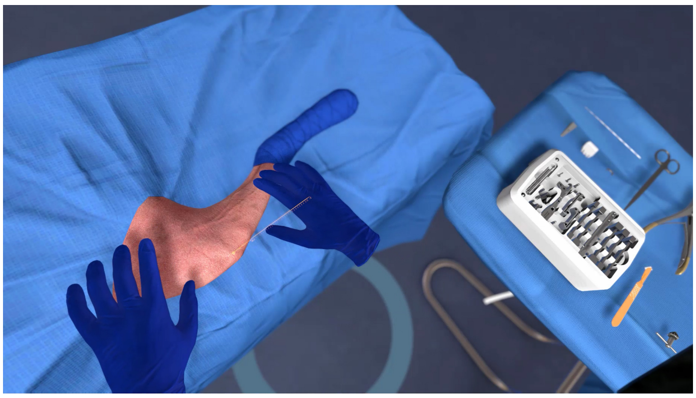

Figure 2.11: Canine cruciate ligament repair surgery [39].

Here, again, the results showed significant success, in fact, VR trained surgeons perform up to 306% better than non-VR trained surgeons [40].

Chapter 3

Project Implementation

3.1 Introduction

The goal of this project is to implement an accurate simulation of an equine respiratory endoscopy, allowing students to practice the procedure on a virtual horse model. Specifically, the key elements required to reproduce a realistic endoscopic examination have been implemented, which include the student's use of the endoscope to navigate and the generation of pathological conditions that the student must be able to recognize during a real examination.
This work builds on a previous thesis done by a student at the Politecnico di Torino, extending it and implementing the new features mentioned. The platform used for the development of this project is Unity [46], with the help of tools such as Blender [23] for modeling and Houdini [44] or Blender for fluid simulations. The simulation can be performed through Oculus Quest 2 thanks to the implementation of the OpenXR library in Unity.
In this chapter, changes made to the previous thesis, improvements, and new implementations will be discussed. In addition, the diseases requested by Professor Bullone will be examined, first from a theoretical point of view and then describing how they were implemented in Unity.

3.1.1 Internal model rework

Part of the work done in this thesis also consisted in reworking the internal model of the horse. This was imported into Blender and completely remeshed, so as to remove holes and other spurious components, as well as to reduce the number of vertices, especially where they were not needed. The larynx, which is the organ responsible for controlling the flow of air through the respiratory tract during breathing, was heavily remodeled. Its movements are managed through an armature system, and more bones are used so as to accurately represent the flexibility

of the arytenoid cartilages. The epiglottis has also been provided with bones in order to animate it properly when required.
The handling of the collider has also changed: in view of the simpler collisions in Unity, the colliders have been managed as a segmentation into various low vertex meshes of the original mesh, as shown in Figure 3.1.

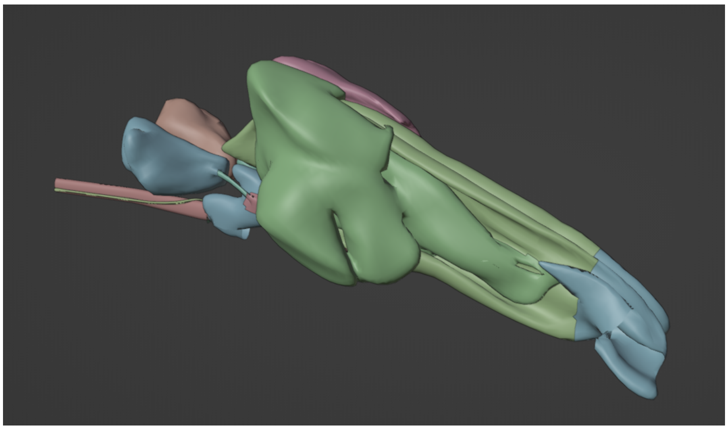

Figure 3.1: Collider segmentation of original mesh by zones

An erroneous result from the CT scan, concerning the entrance into the trachea or oesophagus, was also fixed. Through a consultation with Prof. Bullone, the oesophageal sphincter, and its opening or closing mechanism were correctly implemented.
Finally, a new procedural texture more closely resembling the appearance of flesh and thus more realistic was created with the respective UVs (Figure 3.2 and 3.3).

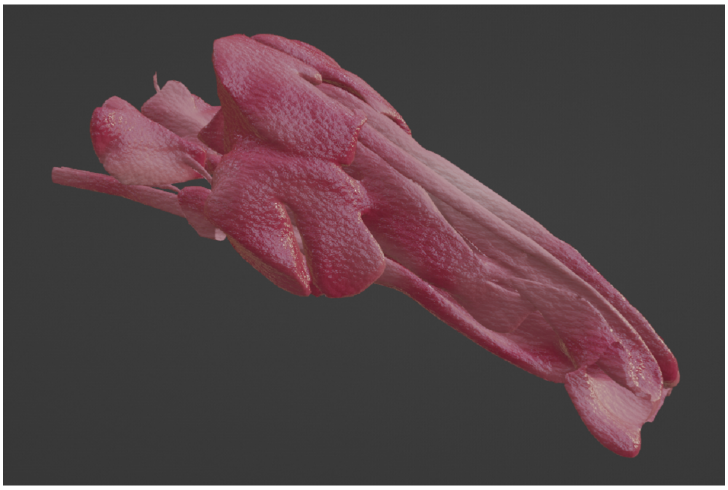

Figure 3.2: Internal model texture procedurally textured in Blender

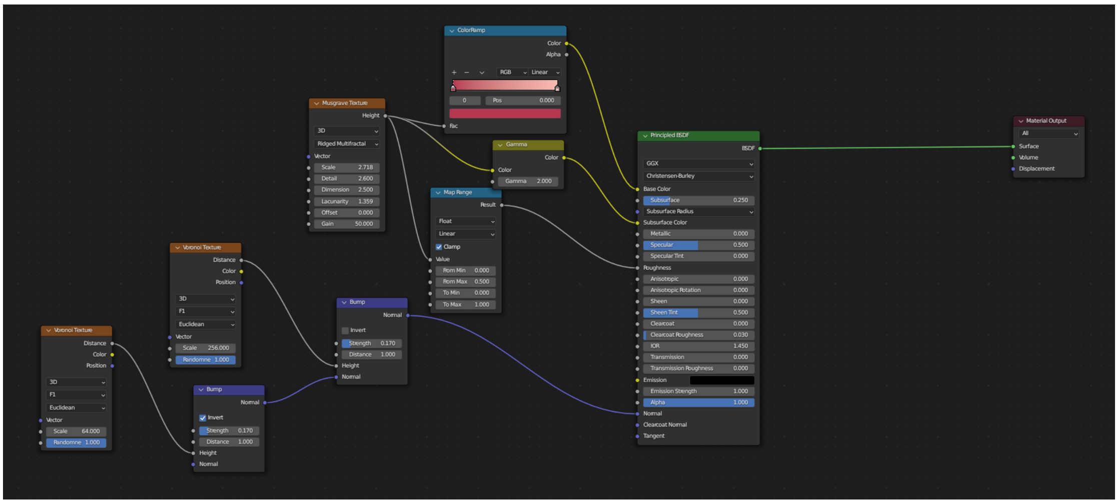

Figure 3.3: Shading flesh material nodes in Blender shader editor

3.2 Theoretical description of diseases

In this section, a collection of all the diseases or conditions that the various students will need to be able to correctly identify within the application will be described. First, the conditions will be shown from a theoretical point of view, and then it will be explained how these were studied and implemented in the experience. For each condition, the area where it occurs in the upper airways and which typical clinical signs the student should look for will be specified. Moreover, the effect of sedation (if performed) and the nostril capping maneuver effects on the disease are reported for each pathology. Finally, the kind of action to be taken if such a problem is encountered will be pointed out.

3.2.1 Recurrent laryngeal neuropathy (RLN) and effects of associated surgical procedures

Also known as laryngeal paralysis, idiopathic laryngeal hemiplegia, or "roaring".

zone: Larynx

subzone: Arythenoid cartilage(s)

clinical signs:

- Exercise intolerance
- Classic “whistling” or “roaring” noise heard during exercise
- Sound of the horse’s whinny may change

what to do: Alert and suggest stress test

Left laryngeal hemiplegia

Left laryngeal hemiplegia is a condition that affects the left side of the larynx in horses and it is characterized by paresis or paralysis of the left arytenoid cartilage and it causes a partial obstruction of the airway. The severity of this condition is usually graded using a scale from grade 1 to 4, with higher grades indicating more severe paralysis, as seen in Table 3.1 and Figure 3.4.
Right-sided hemiplegia and bilateral (paraplegia) arytenoid dysfunction are uncommon. Treatment of the condition involves tie-back or reinnervation surgery. Sedation can cause false positives, and plugging the nose can also induce the condition [42] [5].

Grade	Description
1	All arytenoid cartilage movements are synchronous and symmetrical with full abduction achieved and maintained
2	Arythenoid cartilage movements are asymmetrical or asynchronous at times but full abduction achieved and maintained
3	Arytenoid cartilage movements are asynchronous and/or asymmetrical and full abduction can’t be achieved and maintained
4	Complete immobility of the arytenoid cartilage and vocal fold

Table 3.1: Grading system of laryngeal function [5].

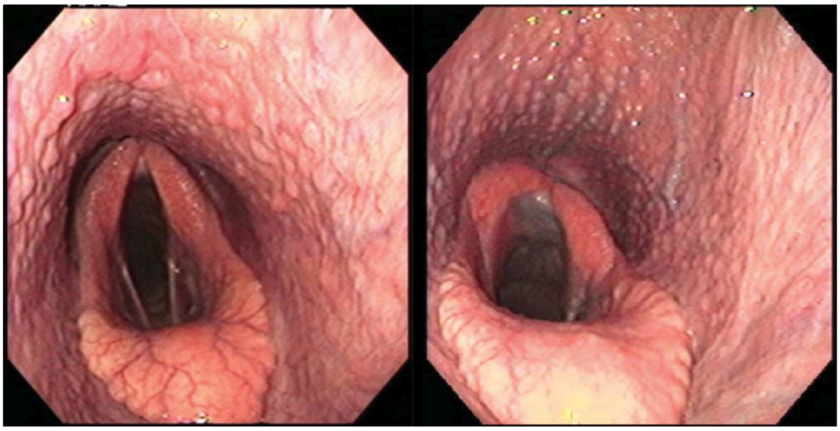

Figure 3.4: (a) Grade II: all major movements are symmetrical with full range of abduction or adduction [4] and (b) grade III: asynchronous, incomplete abduction [4].

Tie-back and reinnervation surgeries are two common surgical procedures used to treat left laryngeal hemiplegia in horses.
Tie-back surgery, also known as laryngoplasty or ventriculocordectomy, involves permanently opening up the affected side of the larynx by placing a suture or implant to hold the arytenoid cartilage in a more open position [4]. This allows for better airflow during exercise, but can also lead to an increased risk of aspiration pneumonia due to the inability to completely close the larynx.
Reinnervation surgery, also known as a nerve-muscle pedicle graft, involves transplanting a healthy nerve and muscle tissue from another part of the horse's body to the damaged recurrent laryngeal nerve in the larynx [4]. This can help restore some of the function of the affected muscle, but the success rate of the procedure is variable and may not be appropriate for all cases of hemiplegia.

Removal of the ventricle and vocal fold

This is a condition where the vocal cords are removed (ventriculocordectomy) to increase airflow and reduce noise as the horse breathes, alone or along with a prosthetic laryngoplasty [9].
Sedation and nose plugged have no effect.

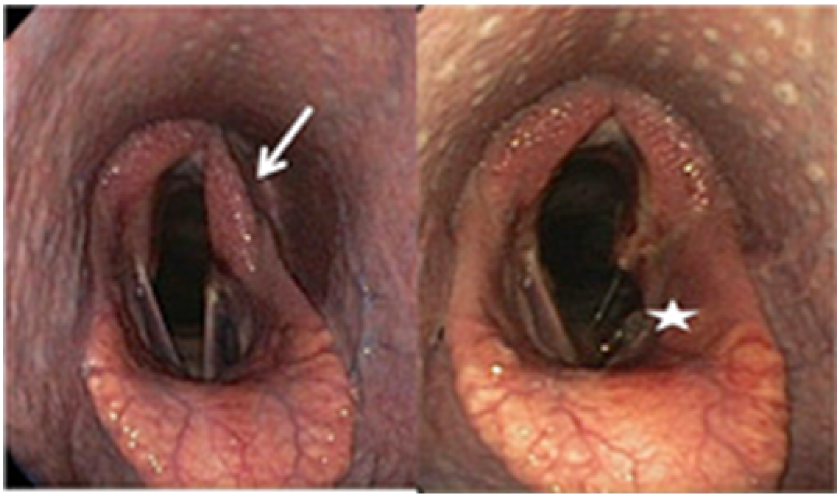

Figure 3.5: Grade IV paralysis (a) pre-operatively and (b) post-operatively after a tieback and ventriculocordectomy procedure [26].

Fixed abduction of an arytenoid cartilage

Index of previous tie-back surgery, where the cartilage is pulled to the side and sutured to keep it from interfering with the flow of air, but it does not produce a completely normal airway (Figure 3.6). Surgical procedures could make horses somewhat more susceptible to pulmonary inflammation and infection [5].

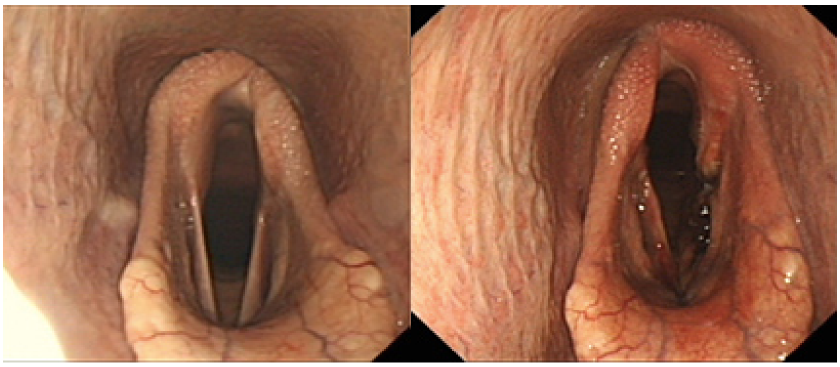

Figure 3.6: Larynx (a) before tie-back and (b) after a tieback and ventriculocordectomy [9]

Fixed adduction of an arytenoid cartilage

Index of previous reinnervation surgery if associated with the absence of respiratory noise in operation. Laryngeal reinnervation has been used successfully in people

and has been shown experimentally to benefit affected horses [9].
Sedation can cause false positives.

3.2.2 Dorsal Displacement of Soft Palate (DDSP)

It is a common respiratory condition in horses. The soft palate is a flexible tissue that separates the oral and nasal cavities, and it is essential for breathing and swallowing. With DDSP, the caudal portion of the soft palate rests above the epiglottis. DDSP can be fixed or intermittent. With intermittent DDSP, swallowing can replace the palate in its proper position [4] [52].

zone: Nasopharynx

subzone: Soft Palate

clinical signs:

- characteristic gurgling noise; and less often, respiratory obstruction
- variable drop in performance associated with acute dyspnea

what to do: Induce swallowing by repositioning (may not work if DDSP is fixed)

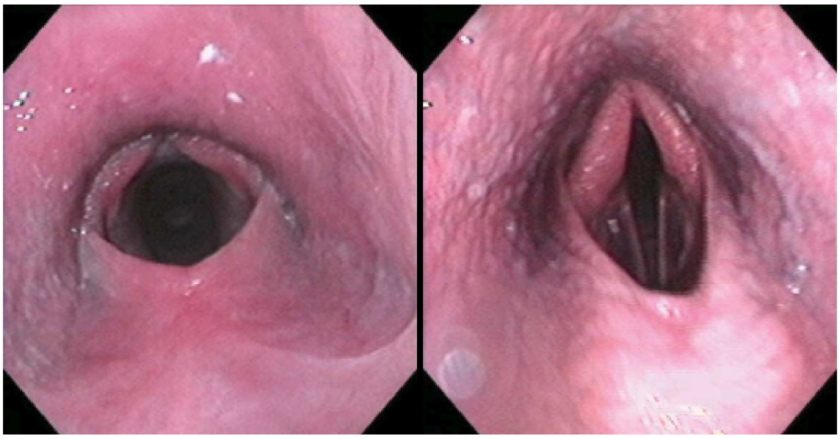

Figure 3.7: (a) and (b) Dorsal displacement of the soft palate [4]

3.2.3 Ethmoid hematoma

Ethmoid hematoma is a rare and benign neoplasm that resembles a tumor in appearance and development but is not neoplastic. It arises from the ethmoid turbinates and progressively grows into one or both nasal passages, paranasal sinuses, and nasopharynx, leading to respiratory obstruction and epistaxis [48].

zone: Nasal, paranasal sinuses, nasopharynx

subzone:

clinical signs:

- unilateral nasal discharge
- chronic (e.g., several weeks or months), intermittent, low-grade epistaxis often with dark blood
- In advanced cases, severe nasal obstruction, and abnormal respiratory noise
- facial distortion is rare

what to do: Report. Inform about the possible outcomes and available treatments

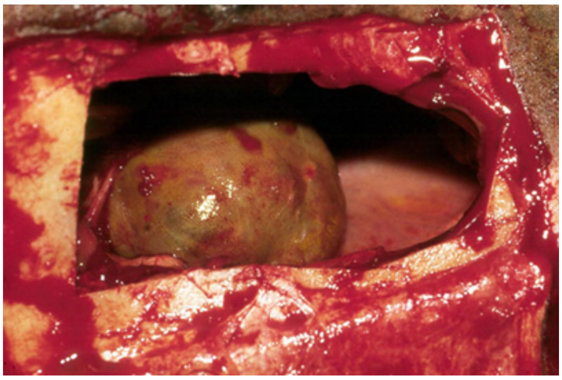

Figure 3.8: Green, rounded, progressive ethmoidal hematoma visible in the frontal sinus of this horse [30]

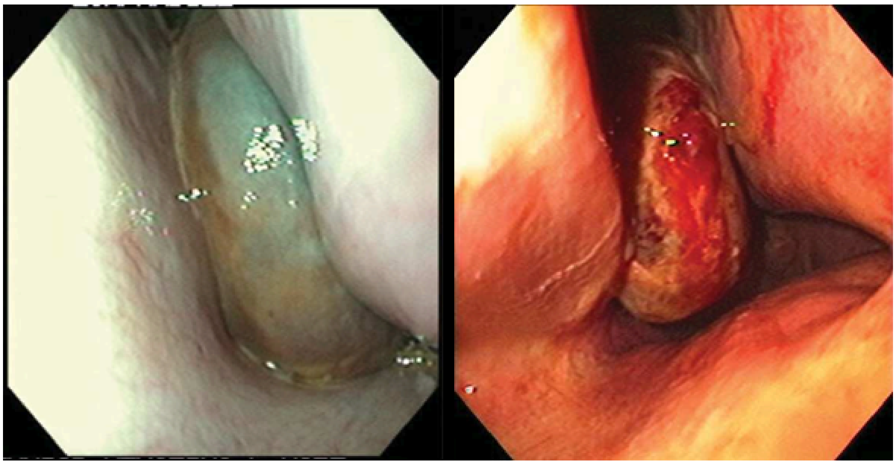

Figure 3.9: (a) Typical greenish coloration of an ethmoidal hematoma [4] and (b) early-stage ethmoid hematoma within the nasal cavity [4].

3.2.4 Pharyngeal lymphoid hyperplasia (PLH)

PLH is characterized by the hyperplasia (increased volume) of pharyngeal lymphoid tissue within the submucosa of lateral and dorsal pharyngeal wall, and particularly around the dorsal pharyngeal recess. This condition is graded based on the size and extent of the lymphoid tissue enlargement (Table 3.2 and Figure 3.10). The lymphoid tissue forms small masses or nodules that can partially obstruct the airway, especially reducing nasopharyngeal tone and causing its dynamic collapse during breathing, leading to respiratory problems and decreased performance. Occasionally, follicles may enlarge and coalesce with surrounding follicles [43] [51].

zone: Nasopharynx

subzone: Soft Palate, Dorsal pharyngeal wall, Lateral pharyngeal wall, pharyngeal recess.
clinical signs:

- Associated with abnormal respiratory noise at exercise

what to do: Establish the grade (1-4). Communicate that self-limiting pathology

Grade	Description
0	no evidence of follicular hyperplasia
1	a few small, white lymphoid follicles scattered over the dorsal pharyngeal wall. Appear inactive and shrunken
2	mainly small, white follicles with occasional larger pink follicles over the dorsal pharyngeal wall and extending laterally to the level of the guttural pouch ostia
3	pink and white follicles covering the entire dorsal and lateral pharyngeal walls often also involving the dorsal surface of the soft palate
4	larger pink, edematous follicles covering all visible mucosa of the pharynx, and sometimes including polyps

Table 3.2: Grading system of the pharyngeal lymphoid hyperplasia [51]

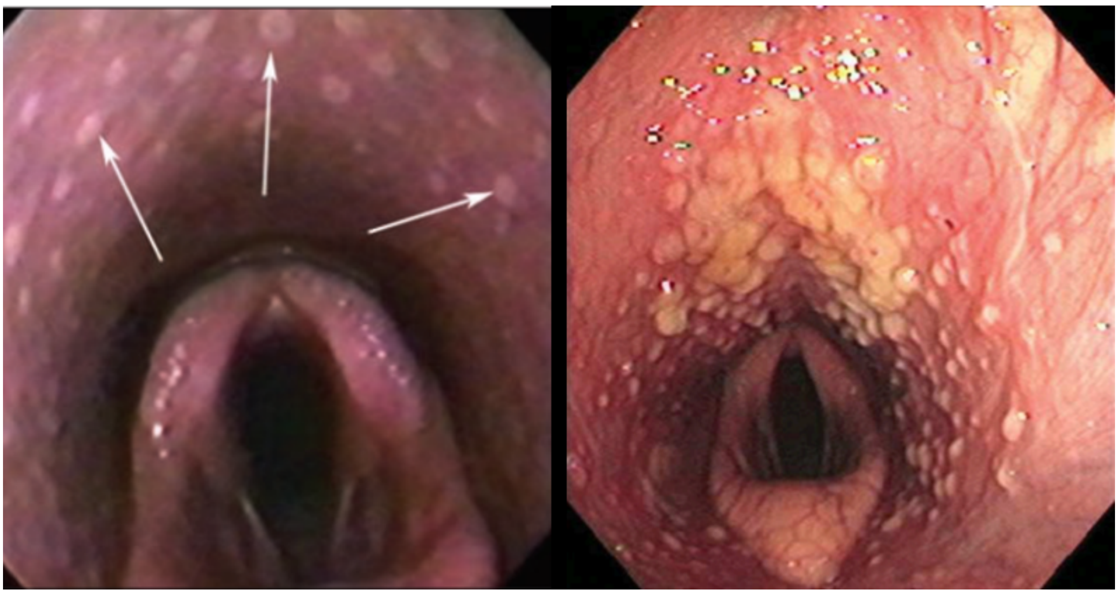

Figure 3.10: (a) PLH grade 1 characterized by small whitish follicles [6] and (b) grade 4 characterized by small masses that arise from either dorsal pharyngeal recess or pharyngeal walls [4]

3.2.5 Guttural pouch melanosis

The guttural pouches are lined with a thin layer of tissue that can become discolored due to an excessive accumulation of pigmented cells known as melanocytes, as shown in Figure 3.11. This pigmentation is often brown to black in color and can be seen on the surface of the tissue lining the pouch. Melanomas are often situated in the lateral compartment, on or near the external carotid artery (ECA) or maxillary artery (MA). These are usually very slow-growing, and hence rarely cause clinical signs. Malignant neoplasms of the guttural pouches are rare [5] [47].

zone: Guttural pouch

subzone: Lateral compartment, ECA, MA

clinical signs:

- Dysphagia and weight loss
- Dyspnea may be seen if significant airway obstruction is present

what to do: Report. Inform about the possible outcomes

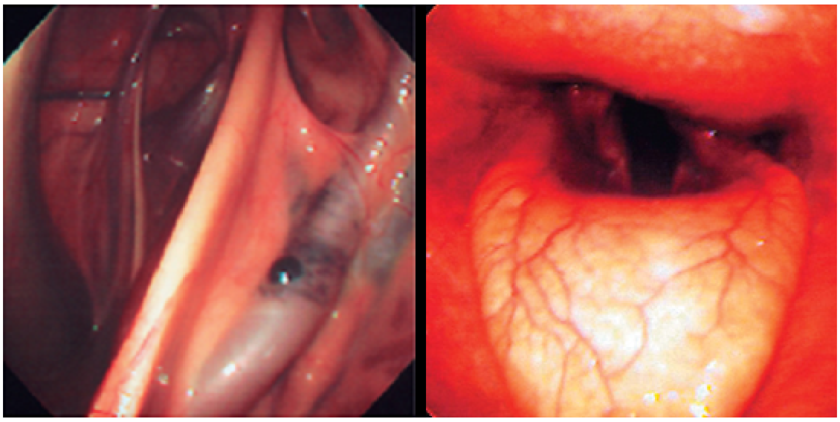

Figure 3.11: (a) Small area of melanosis on the ECA in the lateral compartment [5] and (b) Dorsal nasopharyngeal collapse due to a large melanoma [5].

3.2.6 Guttural pouch empyema

Guttural pouch empyema is caused by a bacterial infection that can result from a variety of sources, including respiratory infections, dental disease, or foreign bodies in the nasal cavity. The infection causes inflammation and accumulation of pus in the guttural pouches. It is commonly associated with infection with Streptococcus equi, var. equi. The examination will enable the clinician to determine the extent of fluid and exudate accumulation and definitively determine whether the disease is unilateral or bilateral. [49] [38] [41]

Chondroids

Chronic guttural pouch empyema may lead to the stagnation of purulent material within the pouch (Figure 3.12 (a)). Stagnation leads to inspissation of pus which may subsequently result in chondroid formation (Figure 3.12 (b) and 3.13). Upper airway endoscopy will provide diagnostic confirmation for the presence of exudate within the guttural pouches. Removing condroids from the guttural pouches can be challenging and may cause a seemingly healthy horse to shed infectious bacteria persistently. Small chondroids can be removed easily by flushing the pouch itself, larger ones require surgery [5].

zone: Guttural Pouch

subzone: Ventral portion

clinical signs:

- Unilateral (or bilateral), purulent nasal discharge
- Loss of performance
- Swelling in the parotid region
- Inspiratory dyspnea/dysphagia if pouch very distended
- Epistaxis (rare compared with GP mycosis)

what to do: Report. Perform guttural pouch lavage to confirm S. equi carrier status

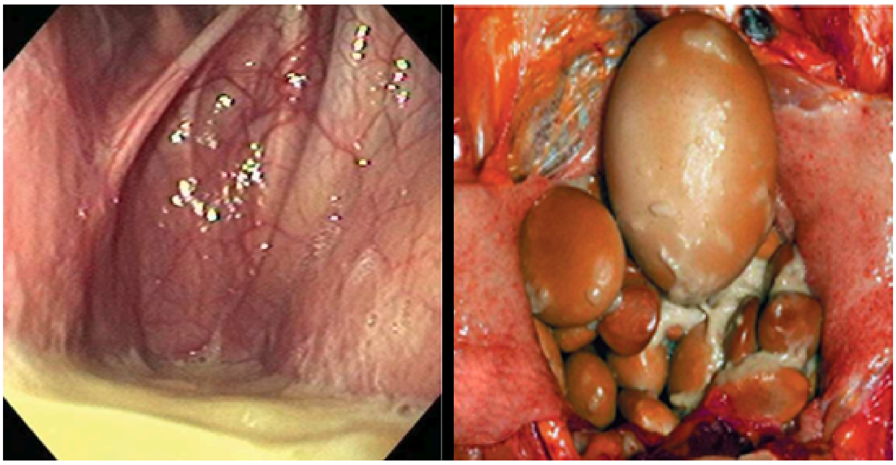

Figure 3.12: (a) Accumulation of pus that forms a puddle within the guttural pouch [4] and (b) large chondroids within the guttural pouch [5].

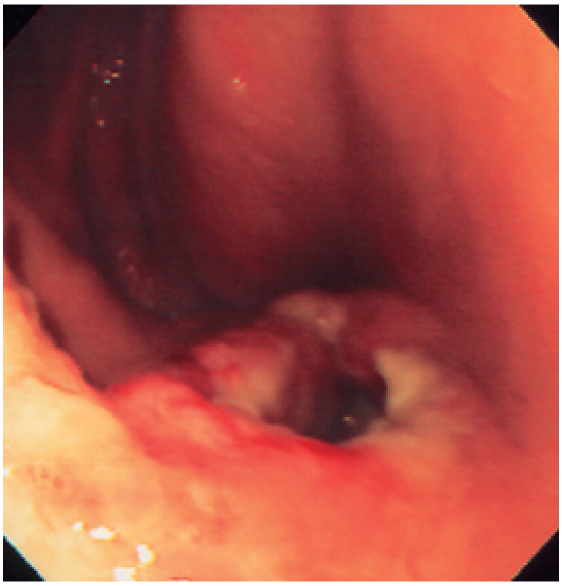

Figure 3.13: Floor of the medial compartment of the left GP in a horse with several chondroids removed surgically [5]

3.2.7 Guttural pouch mycosis (GPM)

Aspergillus fumigatus, an opportunistic respiratory pathogen, is responsible for mycotic infection of the guttural pouch. The fungus often erodes the major blood vessels that lie just below the mucosa of the pouch as seen in Figure 3.14 (b), causing moderate or massive arterial epistaxis, sometimes visible from the ostia, as in Figure 3.14 (a) [50] [41] [38].

zone: Guttural Pouch

subzone: Internal carotid artery (ICA), ECA, MA, or diffuse

clinical signs:

- moderate or massive arterial epistaxis
- swelling of the ipsilateral submandibular lymph nodes and parotid region
- dyspnea

what to do: Report. Suggest emergency treatment

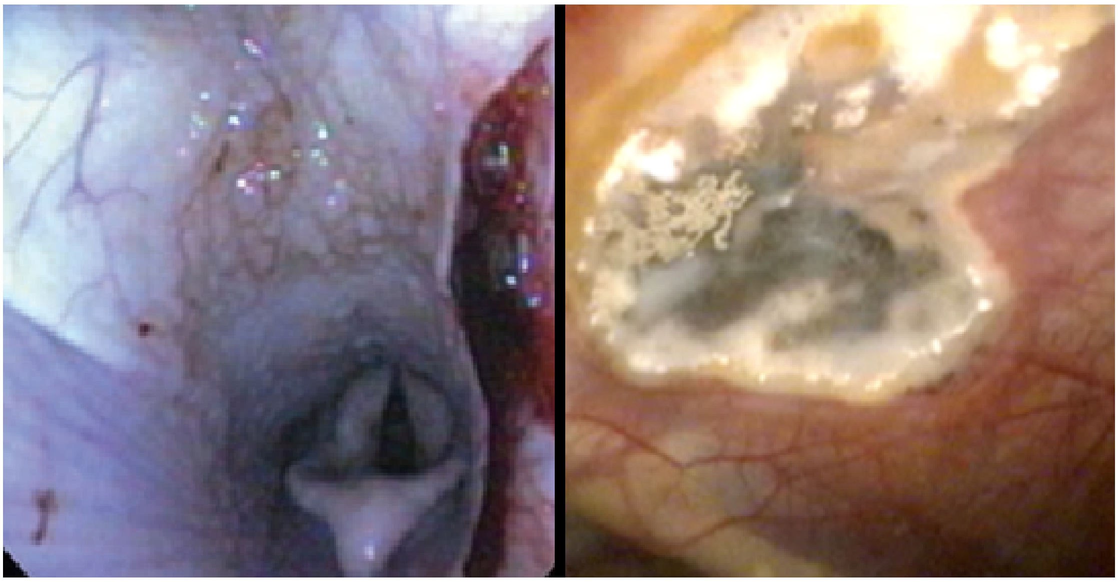

Figure 3.14: (a) Blood leaking from the ostia of the guttural pouch due to epistaxis [6] and (b) Fungal plague affecting the dorsal wall of the guttural pouch [27]

3.3 Explanation of conditions implementation

This section will show the implementation choices of the various diseases or conditions seen previously through the Unity engine.

3.3.1 Clinical signs commonly linked with certain diseases

Swelling

Some diseases, such as melanoma or empyema, have swelling as a symptom. To implement this, a mesh deformation was chosen, at vertex level. The vertex that is translated by a certain value is picked and so are the neighboring vertices but with a certain falloff (an approach very similar to the proportional editing proposed by Blender). This simulates well the behavior of cancer cells that tend to expand by growing disproportionately. For vertex selection, a customized editor was used

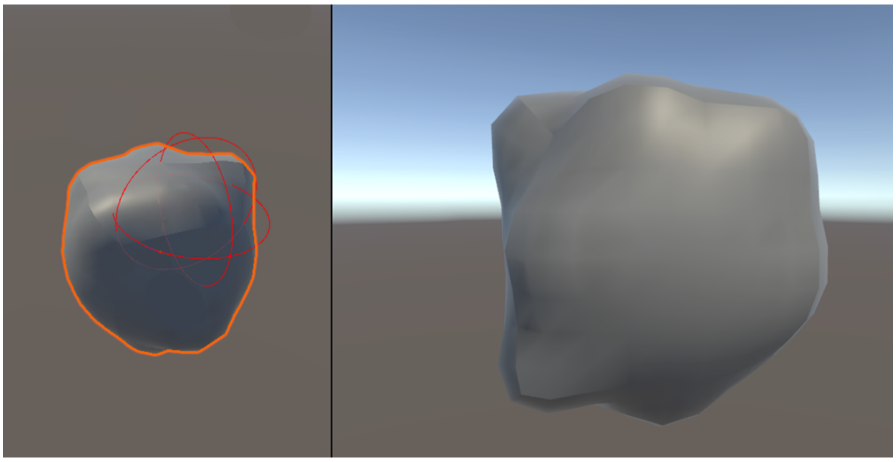

Figure 3.15: Deformation with a fall-off that follows gauss's law (bell). The red wiresphere indicates the last key point that experienced the force due to deformation

to display and choose vertices in order to apply deformation only in the area of interest. This list of vertices will then be stored within scriptable objects, a feature in Unity that allow to create custom, reusable data containers, and will be called up during deformation.
To prevent the deformation from having a permanent effect, prior cloning of the mesh is carried out in Unity. In summary, a new mesh is created having the same vertices, triangles, normals, uv texture coordinates, and blendshapes for possible animations. Any deformation will then be applied to the cloned mesh and when necessary it is possible to return to the initial situation. The same applies to the collider mesh, which receives the same treatment as the original mesh. However,

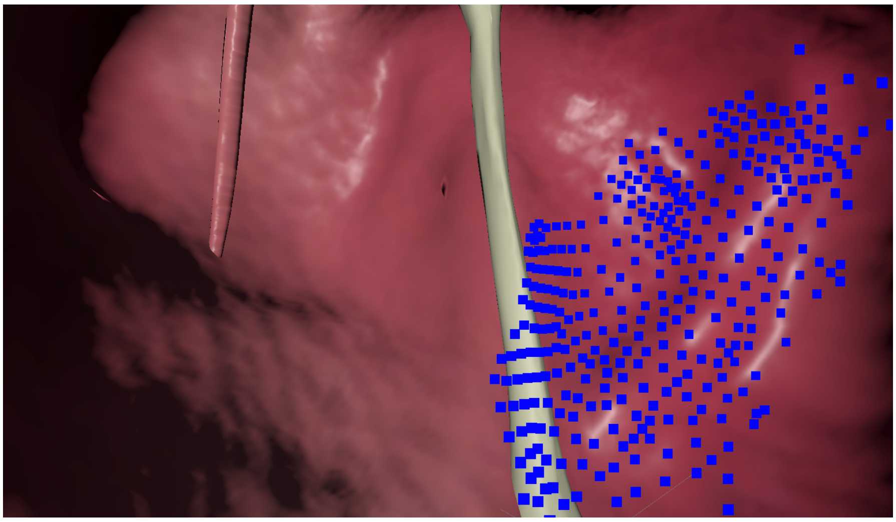

Figure 3.16: Manual selection of vertices for identifying sub-areas (in this case sub-area External Carotid Artillery) using the TEST_Vertex Get script. The vertexes are blue clickable buttons placed on the mesh.

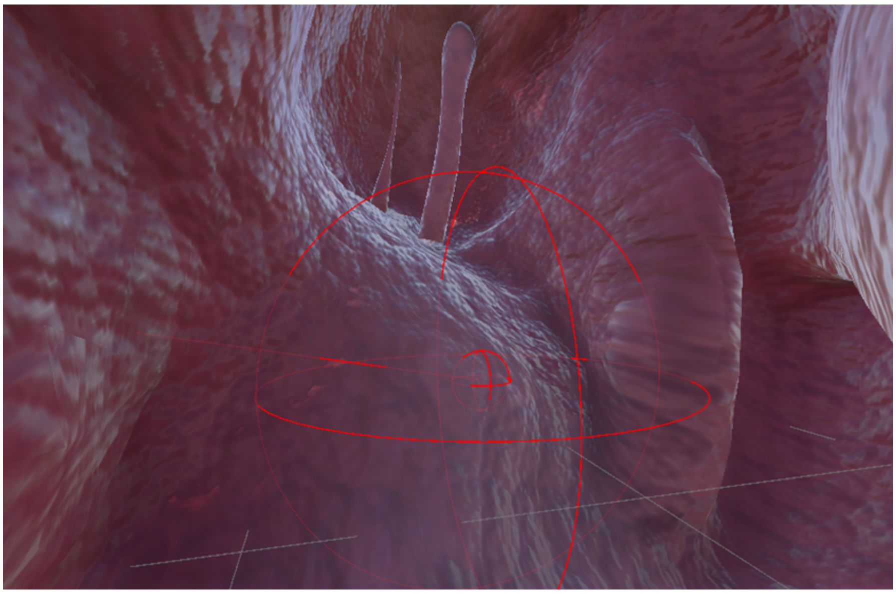

Figure 3.17: Final result of mesh swelling deformation due to melanoma expansion. The little wiresphere indicates the key point, while the big ones is the radius of influence.

since it has a different structure as it is more simplified, the vertex that undergoes the deforming force is selected by taking the one closest to the original mesh, in terms of distance.

Hemorrage

The basic element of some diseases is bleeding, possibly associated with epistaxis. For that reason, there was the bleeding problem that had to be addressed. Excluding fluid simulation, which is overly expensive, a strategy that is not too dissimilar was considered. Firstly, it was necessary to create the appropriate textures. Fluid simulation in Blender and Houdini was used to find realistic textures and in particular, mimic the spatter effect, as shown in Figure 3.18 (a). From the splash models, intersections with a plane were extracted as grayscale textures (Figure 3.18 (b)), then fed into unity after some rework in Photoshop.

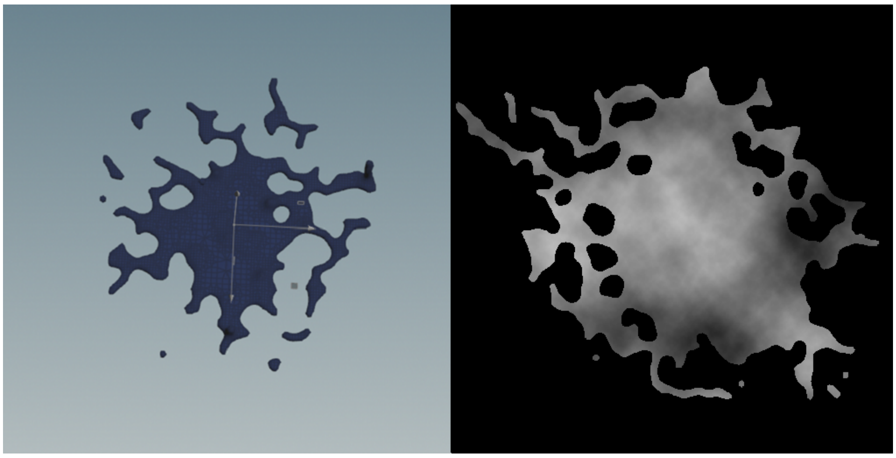

Figure 3.18: (a) Splash model made with Houdini's fluid simulation and (b) the texture representing the that model

Secondly, it was required the creation of a suitable shader in Unity. The previously created texture is an alpha map and is used as an interpolating function for light and dark colors (red in the case of blood) to give a sense of depth.
Also within the shadergraph a sample noise properly remapped and inserted as an alpha in the fragment shader allows the transparency to be adjusted by parameter, so as to provide a drying effect needed later for the simulation.
Normal texture is taken directly from the image thanks to an apposite Normal From Texture node provided by Unity.

Finally came the simulation part, where different approaches were experimented with before a satisfactory solution was found.

- Spawn secretion
  This attempt is based on a search for different vertices belonging to the mesh into which to cast via the projectors provided by Unity (Decals) the materials created with previous textures and shader.

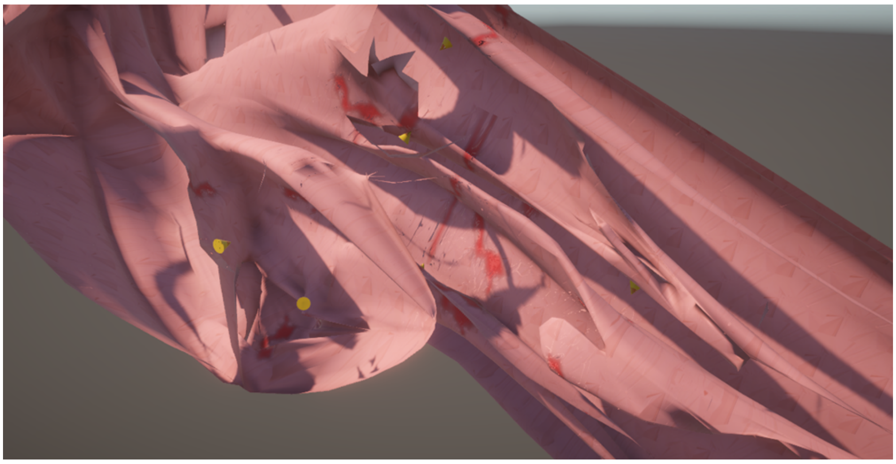

Figure 3.19: Random spawn of projectors inside the mesh. Yellow cones indicate the origin point of the decal.

- Texture edit
  Another solution that has been considered but discarded almost immediately, but which is very interesting, consists of setting up a grid centered around a pixel which is the size of the new texture (in pixels) and setting the old texture's pixels to be the pixels of the new texture. It is interesting because it is in-game permanent (but reset at each launch) and especially no objects are created.

- Fluid simulation-style approach
  This type of effort takes the use of decals considered by the first solution and combines it with a physical simulation.
  The concept is that one or more spheres (depending on the intensity of the bleeding, in terms of volume) that through physics are dropped from the bleeding point. During the path that the sphere travels, points are sampled (3.20), based on the distance between one and the next (to avoid dead spots where the sphere has stopped), and the intensity of the blood (small bleeding stops sooner than large bleeding). Then the path ends either with the intensity

reaching zero, or at the nostril arrival, where it might then drip from the nose. In case of a very high density, several particles propelled in several directions, each with a certain initial velocity, are used to simulate blood squirting (an element that can be added in particle system in case of epistaxis due to contact with the probe). In this way, it is then possible to create a projected trail of blood (decals), which will give the idea of bleeding. The blood may also be fresher (clear), or darker and dried up (old, hemorrhage now finished)

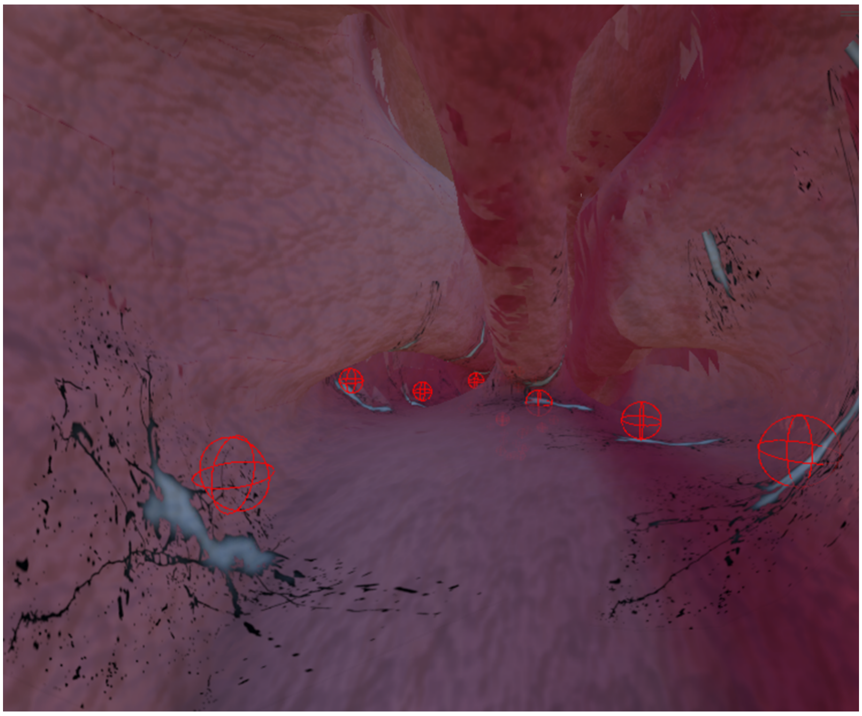

Figure 3.20: Random spawn of projectors inside the mesh. Red wirespheres are the sampled points on the sphere path.

Blood elements have different "fluid levels" based on their proximity to the wound. The "Dryness" parameter in the shadergraph controls this factor and ranges from 0 to 100, indicating the degree of reduction (drying) of the blood as it moves away from the wound. This parameter is based on the time taken by the sphere to reach a specific point in its path.
Three are the parameters that affect blood spawn:
Density: The drying level of the various blood stains along the pathway
Intensity: Indicates the amount of blood that is emitted, i.e., the number of simulation spheres generated
Violence: Symbolizes how violent the bleeding is, hence the initial force with which spheres are instantiated

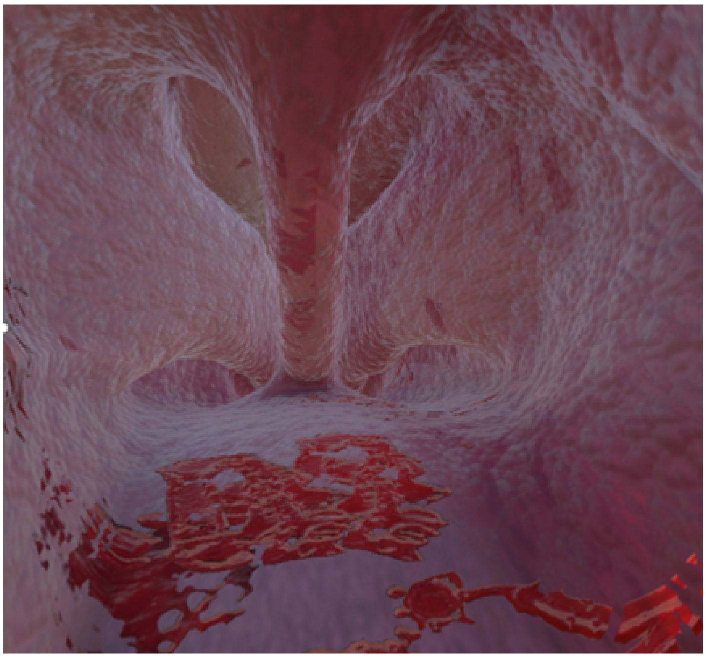

Figure 3.21: Epistaxis in the Nasopharynx, caudal view (irrealistic in vivo)

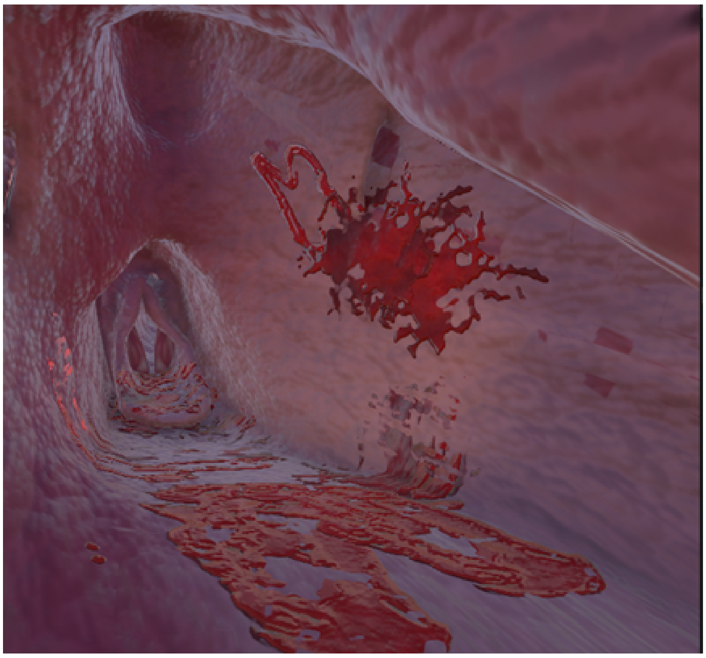

Figure 3.22: Same hemorrhage, cranial view (realistic in vivo image). Note the blood on the GP ostia

3.3.2 Left laryngeal hemiplegia

As described before, the left laryngeal hemiplegia influences the left arytenoid cartilage of the larynx. Initially, a high level of accuracy was required in implementing the larynx as it played a crucial role in the overall success of the project.

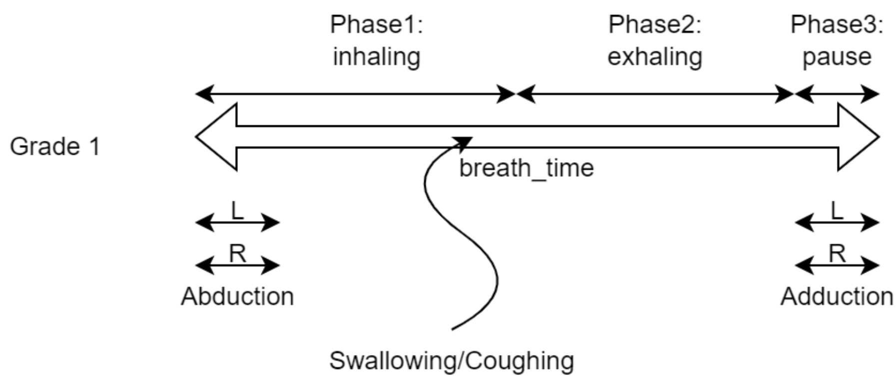

Figure 3.23: Inhaling and exhaling scheme. Swallowing and coughing are handled asynchronously

Following the model's import and thorough examination, the focus shifted towards achieving an accurate replication of its behavior. The process involves two phases, inhalation and exhalation, as shown in Figure 3.23. It starts with abduction, during which the two cartilages move apart from each other, widening the diameter of the glottis and reducing resistance to airflow (Figure 3.24).

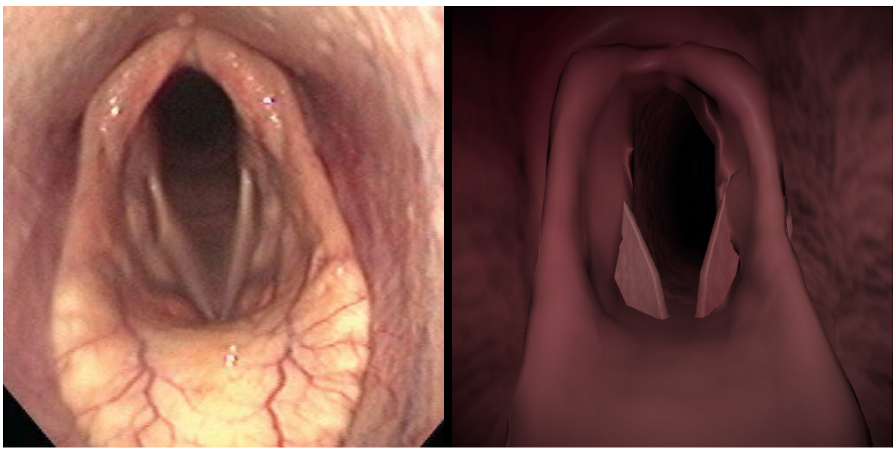

Figure 3.24: Abduction of the arytenoids (a) in real horses [5] and (b) in the project

In contrast, in the process of adduction, the two arytenoid cartilages move closer together, narrowing the diameter of the glottis and increasing the resistance to airflow (Figure 3.25). This movement occurs in the expiratory phase.
Opening and closing are handled via script, thanks to the use of the DOTWEEN library [25], which is a free and open-source object-oriented animation engine designed for Unity, that is fast, efficient, and fully type-safe. It was decided to act in this way in order to parameterize everything and make it easy to override the behavior in the case of RLN.

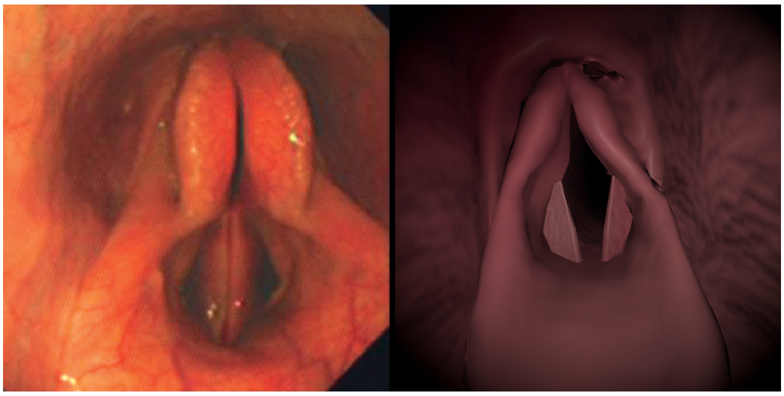

Figure 3.25: Adduction of the arytenoids (a) in real horses [5] and (b) in the project

To implement the various degrees seen in Table 3.1 and thus handle asynchrony and asymmetry, in the first case, the time delays provided by DOtween's SetDelay() [25] function were relied upon, while in the second case, a dead zone concept was utilized, as seen in Figure 3.26.

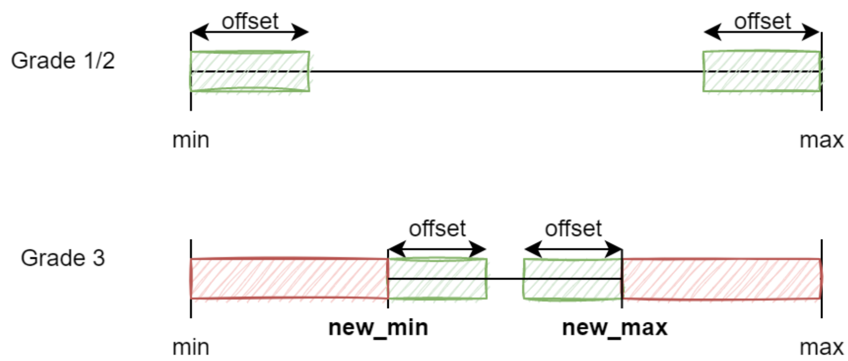

Figure 3.26: Asymmetry scheme: red represents the dead zone, where the arytenoid can't move, green is the interval of randomness

In the case of grade 1 or sometimes 2, there is no asymmetry, so there is only an offset to ensure realism, equal to 20% of the movement in minimum and maximum, for both left and right.
In the grade 3 situation, we have a motion deficit (dead zone) of 30% in min and 30% in max (values that are visually acceptable). This results in a lower range of motion for the left arytenoid.

3.3.3 Removal of the ventricle and vocal fold

This is a condition that the student must be able to detect, and is characterized by the removal of the vocal cord as a result of a ventriculocordectomy, the relative mesh of the left laryngeal ventricle is simply hidden, and with some probability the right one as well.

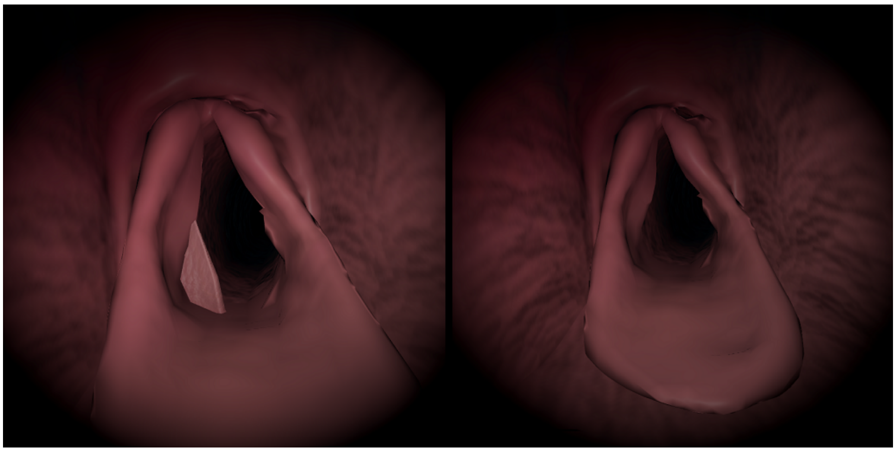

Figure 3.27: Removal of (a) left vocal cord and (b) both vocal cords

3.3.4 Fixed abduction of arytenoid cartilage

It just sets the dead zone of the maximum position of the left arytenoid at 95 percent, thus allowing a very small movement, as if it were tied to the upper extremity. The result is visible in Figure 3.28.

3.3.5 Fixed adduction of arytenoid cartilage

Same as fixed abduction but reversed, that is, the minimum position has a 95 percent dead zone. The outcome can be seen in Figure 3.29.

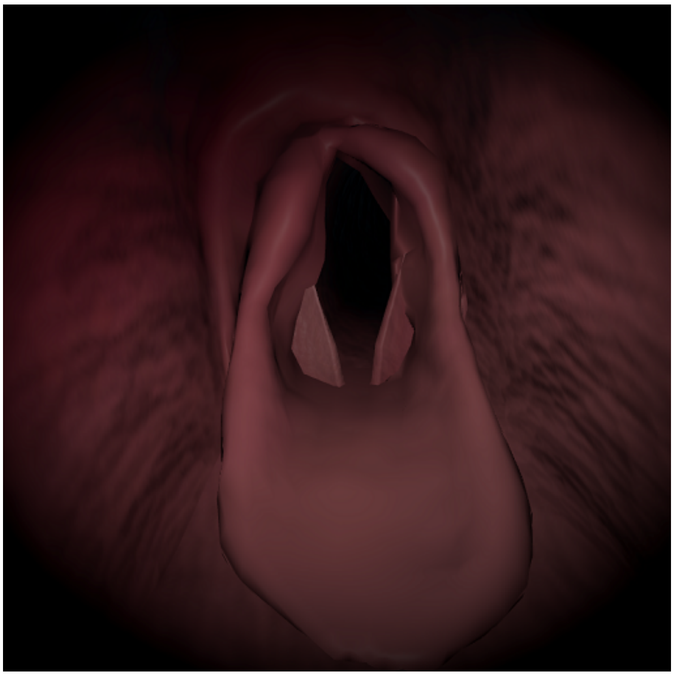

Figure 3.28: Fixed position of left arytenoid after tie-back surgery

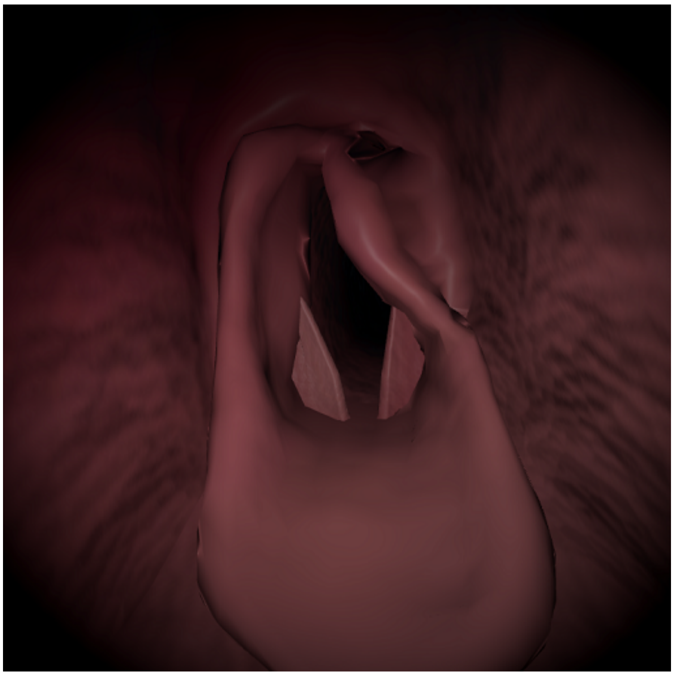

Figure 3.29: Fixed position of left arytenoid after reinnervation surgery

3.3.6 Dorsal Displacement of Soft Palate (DDSP)

To simulate DDSP, the starting mesh of the nasopharynx had to be modified.

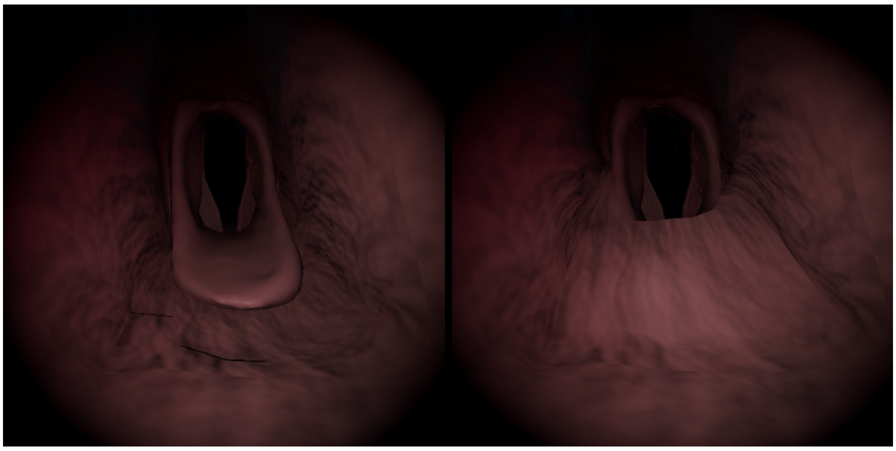

Figure 3.30: (a) Normal condition of the soft palate and (b) lifting of the soft palate trapping the epiglottis

To do this, a shape key was created in Blender, which was then imported into Unity as a blendshape within the SkinnedMeshRenderer component. When the disease is generated, the weight of the blendshape is set to a certain random value. The same is then done for the collider of the nasopharynx, to maintain it updated.

3.3.7 Ethmoid hematoma

An ethmoid hematoma in a horse is a mass of abnormal vascular tissue that develops in the nasal cavity or paranasal sinuses of the ethmoid bone. To create it, it was then decided to use a procedural mesh. Initially, a solution with raycast was considered, but this was abandoned due to problems with the mesh collider (which does not react if the source of the raycast is inside the collider itself). A solution with physics was therefore adopted, similar to the one studied for epistaxis. A directional vector is randomly generated from which the hematoma starts, which then influences the type of nostril it will affect. From here a sphere is launched, which falls with very low gravity toward the nostril, sampling points along its path. These points are then used as bases for cylinders, i.e. meshes of the hematoma. Finally, a mesh collider is added so that the probe can interact with it. The result represents a truncated cylinder with circular cross-sections. The mesh is constructed by iterating through an array of points that define the concentric circles of the truncated cylinder, where the first and last elements of the array represent the top and bottom sections of the cylinder, respectively. For each section,

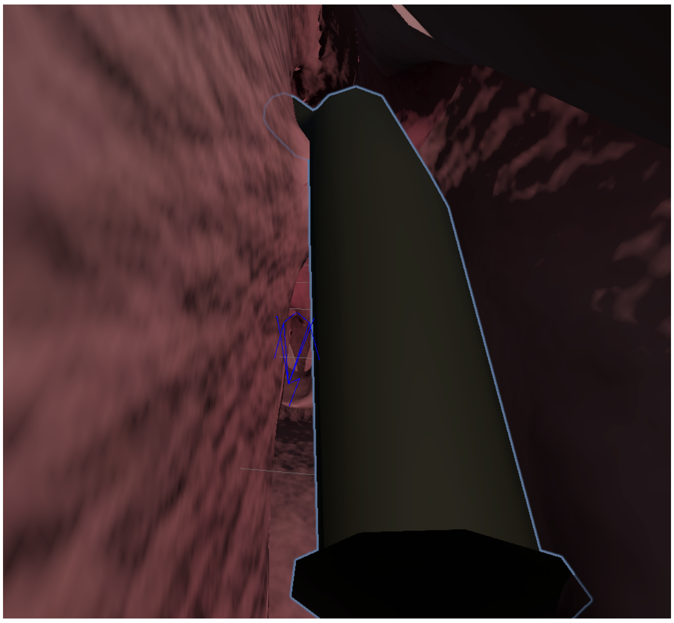

Figure 3.31: Ethmoid hematoma procedural generation as a cylinder sequence

the code calculates a set of vertices for the cross-section of the cylinder with the corresponding radius. These vertices are then used to create the triangles that form the faces of the mesh. On the other hand, for the last circle of points, which represents the fill of the cylinder, triangles are created that connect the centre vertex with the vertices of the circumference.

3.3.8 Pharyngeal lymphoid hyperplasia (PLH)

As seen previously, PLH is characterized by an increased volume of pharyngeal lymphoid tissue within the submucosa, where it forms small masses or nodules. The spread of these masses is obtained through geometry nodes (Figure 3.33) and a collection of spread hemispheres (Figure 3.32) with a distribution dictated by a weight paint from the geometry node attribute (modifier).
After applying the modifier to the 3D model, the resulting mesh is uvmapped in order to generate and export a bake of both the diffuse and normal textures. Once this process is complete, the 3D model along with its associated textures are imported into Unity as separate files for each grade of the disease. Using a simple instantiation process of the corresponding prefab within Unity, the model is then spawned inside the simulation (Figure 3.36).

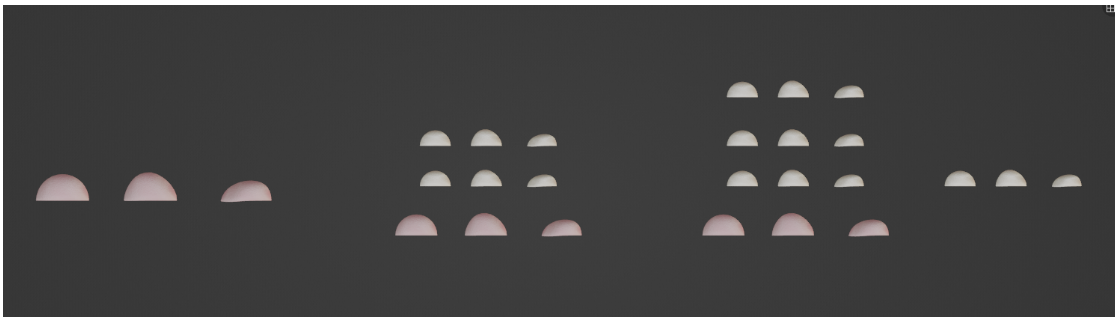

Figure 3.32: The four collections concerning the respective degrees of the disease.

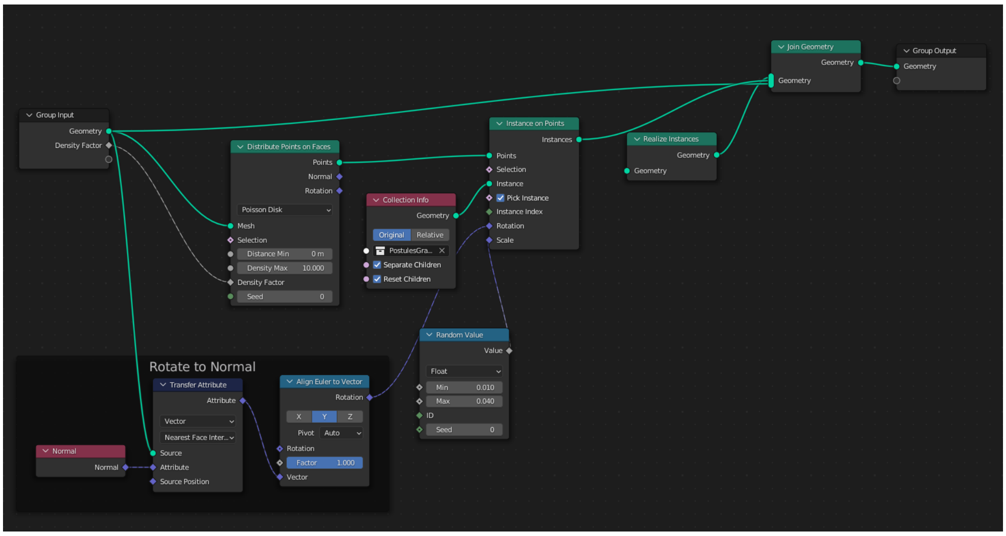

Figure 3.33: Geometry node structure to spawn the follicles on the mesh with a distribution set by vertex groups.

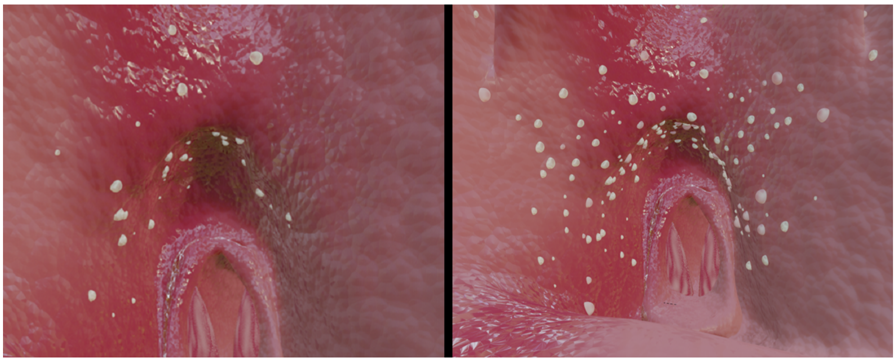

Figure 3.34: LPH (a) grade 1, with small white follicles on the dorsal pharyngeal wall and (b) grade 2, with small white follicles and some large pink ones on the dorsal and lateral wall of the pharynx

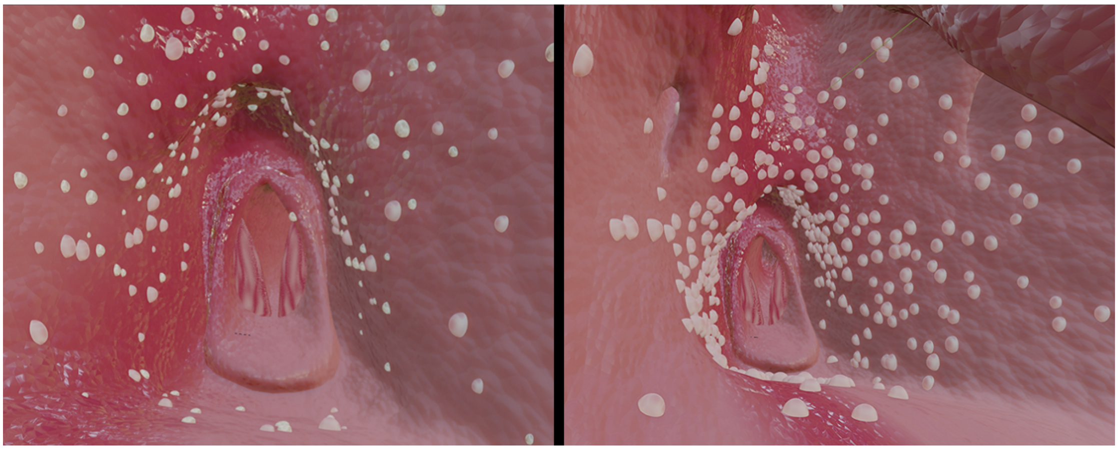

Figure 3.35: LPH (a) grade 3, with white and wide pink follicles on the dorsal, lateral wall, and soft palate and (b) grade 4, with large pink wide follicles on the dorsal, lateral wall, and soft palatel wall of the pharynx

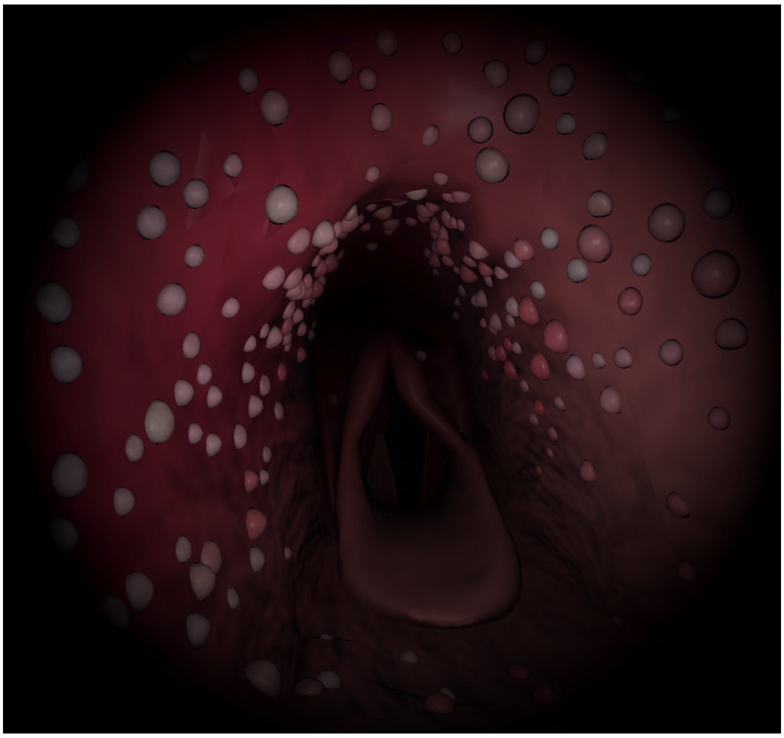

Figure 3.36: Grade 4 LPH inside Unity simulation

3.3.9 Guttural pouch melanoma

The actual Melanoma is implemented firstly by selecting the guttural pouch in which to generate the melanoma: left, right, or both. Within the single pouch, we have more subZones but melanoma is usually generated in ECA (External Carotid Artery). Each of these zones is created via a Scriptable Object that encloses the range of vertices representing it.
There are a couple of ways that melanoma can be detected in the simulation. The first way is through swelling, and in this case, a swelling function is called. This function randomly selects several vertices from the corresponding subzone and then iterates a vertex displacement function.
The second method of detection involves the use of projectors to create a black, ink-like texture in the appropriate sub-area, with a certain probability.

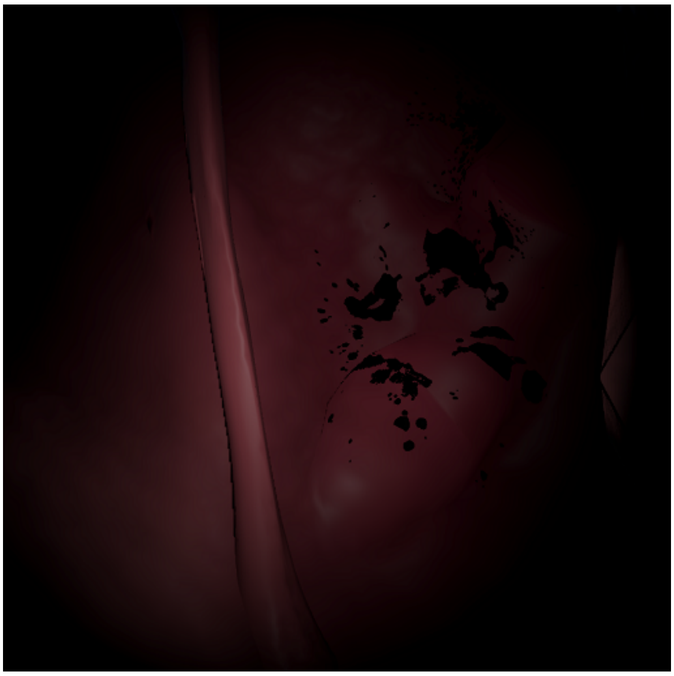

Figure 3.37: Ink-like shape of melanosi on and near ECA

In addition to these two modes, it is possible for the melanoma to expand to the nasopharynx, compromising good respiration. This condition is simulated by a degree of aggressiveness of the melanoma that, if it exceeds a certain threshold, will also deform with swelling the respective subzone in the nasopharynx.

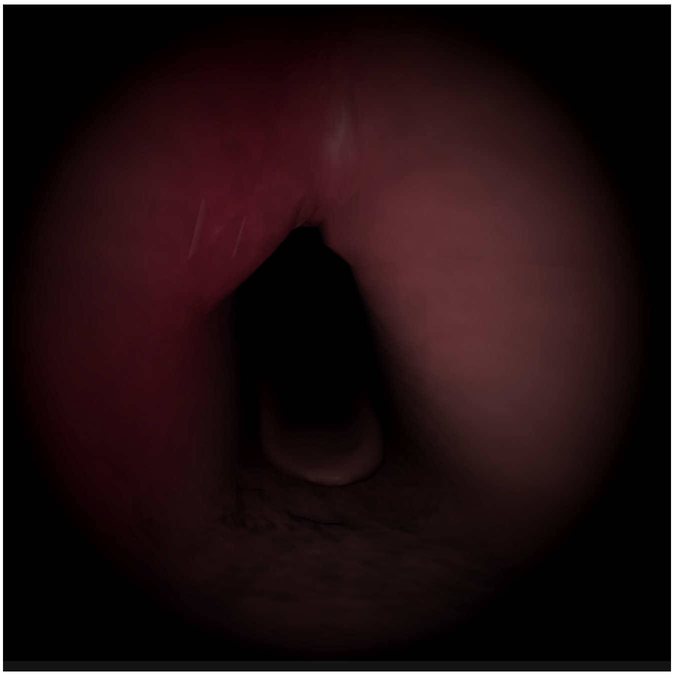

Figure 3.38: Aggressive deformation by a melanoma

3.3.10 Guttural pouch empyema

Empyema is a disease of guttural pouches that affects the lymph nodes in the dorsal roof, and can manifest with swelling with:

- Liquid pus
  A stagnation of pus on the dorsal wall.

- Chondroids
  The pus has solidified, forming spheres.

Liquid pus

In Blender, a plane was modeled with a vertex displacement dictated by a texture formed from a cloud-like fractal noise texture. A simple shader was then applied to this for a color that varied with vertex height to give a sense of depth. These 3D models are then imported into Unity and generated based on the referring guttural pouch. A mesh collider attached to them prevents the probe from passing through.

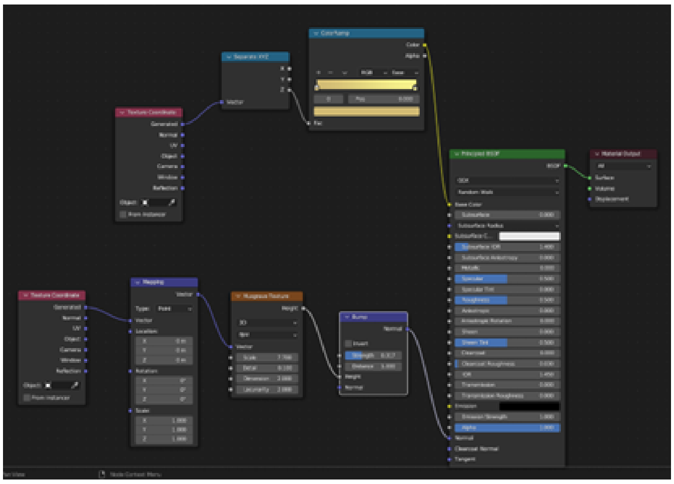

Figure 3.39: Pus shader in Blender

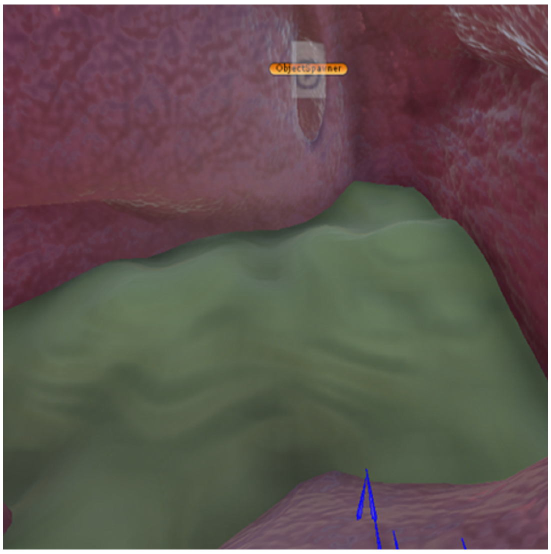

Figure 3.40: Pus pool inside left guttural pouch.

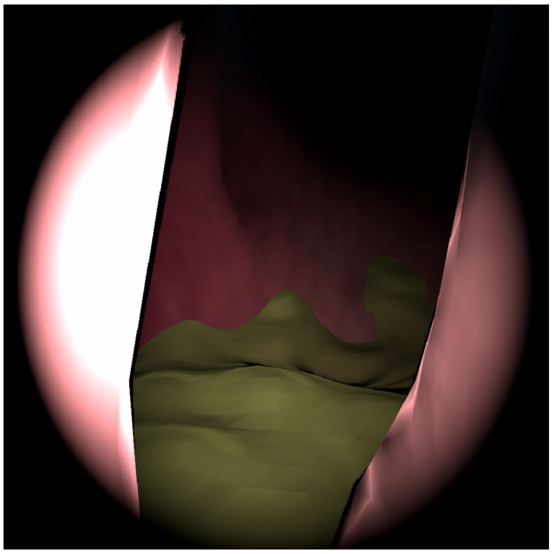

Figure 3.41: Pus view from left Eustachian tube.

Chondroids

In the last case, however, the lymph nodes erupted, leaving grooves in the wall where liquid pus gradually solidified to form chondroids. The hole is created as swelling but with a negative force.
Chondroids, on the other hand, are nothing more than spheres of variable size that are instantiated and where the key (central) points from which it started are

previously saved during the deformation, so as to spawn the Chondroids from that points. These have a rigidbody fall by gravity into or around the hole, which is why it was necessary to implement colliders and their deformation in this part of the project.

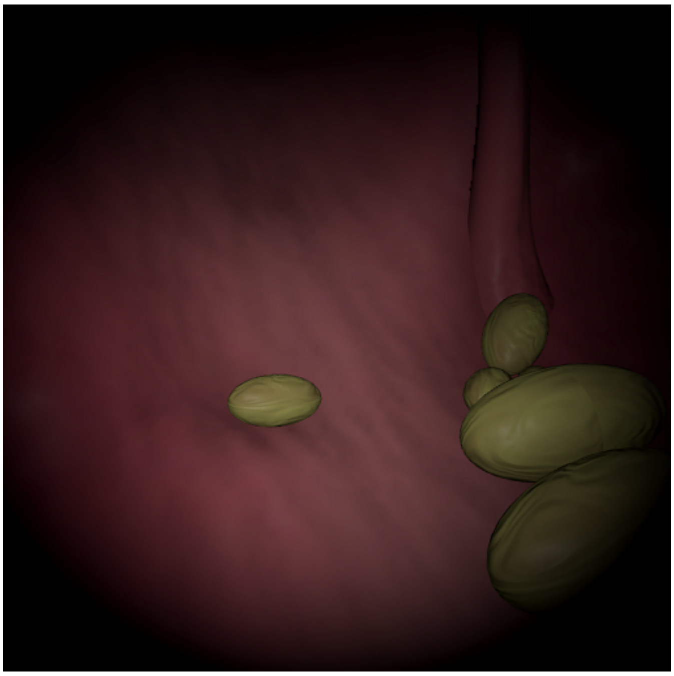

Figure 3.42: Large spheres of solidified pus known as Chondroids on the dorsal roof of the guttural pouch

3.3.11 Guttural pouch mycosis (GPM)

The main element of mycosis is the presence of blood due to epistaxis, which may be fresh or old depending on when the bleeding occurred. This is generated by a particular function that follows the procedure seen before for the epistaxis simulation.

In addition to bleeding, a fungal plague can be found inside the guttural pouch that attaches itself to the arteries, like the ECA, and corrodes them, causing bleeding. To generate it, the usual projector and spawn system seen previously for other diseases is adopted, in the presence of the sub-area representing the dorsal of the medial compartment.

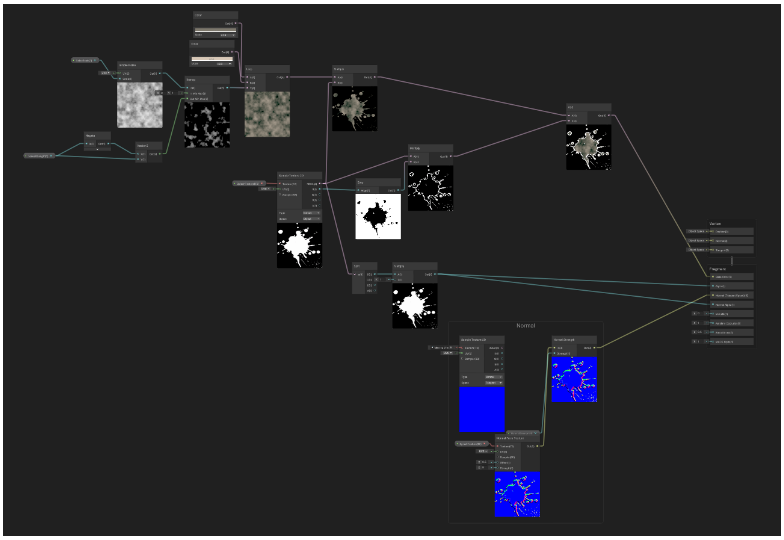

Figure 3.43: Mycosis shadergraph in Unity

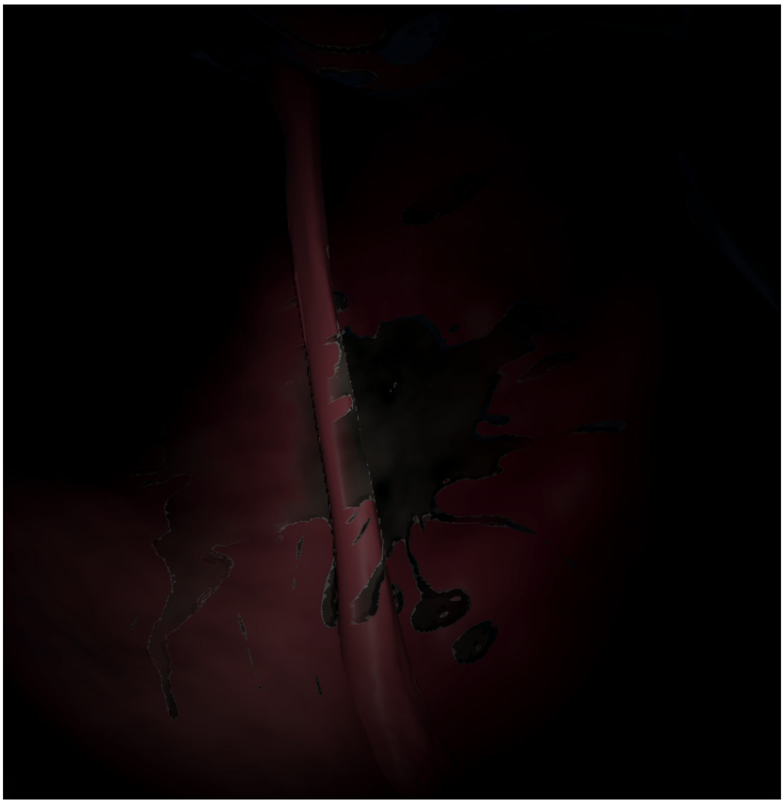

Figure 3.44: Mycosis fungal plague decal

Chapter 4

Application framework

This chapter describes the various implementation aspects of the endoscopic simulation, illustrating the design choices and technical solutions adopted to realize the various functionalities, such as the main menu, tutorial, etc.

4.1 Scaffolding modalities

As previously mentioned, the goal of the application is to provide training support to students. In order to effectively manage the scaffolding process, it is therefore essential that students be able to authenticate themselves within the application.

4.1.1 Authentication

To authenticate, the menu screen, which is the first screen that is presented when the application is run, has to be displayed, as in Figure 4.1. Authentication is handled by saving data online, or if the user prefers offline as well. This allows the user to view its progress at any time and from any device.
Once in the menu, it is possible to view past sessions or define a new one, as in Figure 4.2. A session is defined as an object containing all relevant information from a virtual endoscopy simulation, collected during the endoscopy experience. These contain the elapsed time, the various diseases to be detected, and will be analyzed in detail below.

Figure 4.1: Application menu. On the left is the sign-up button, on the right is the online login button, and at the bottom is the offline login button.

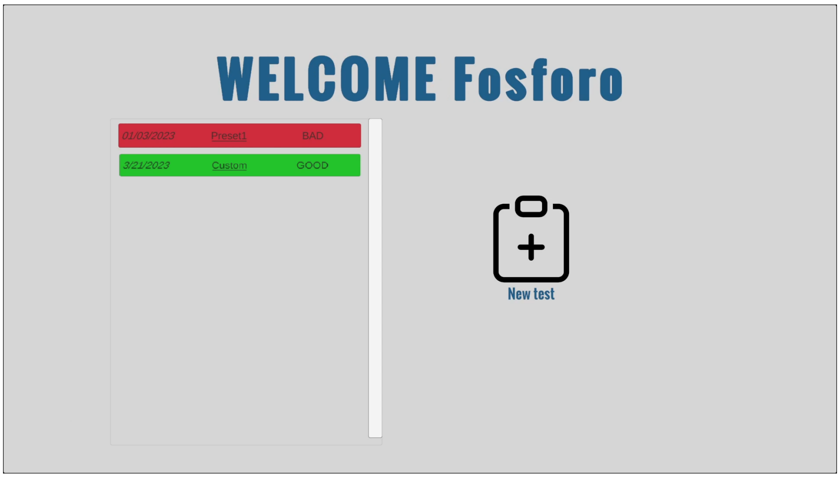

Figure 4.2: Main menu after logging in. On the left is the list of previous sessions where the color indicates the score, on the right is displayed the button to create a new session.

While creating a new session, it is possible to choose from different disease presets or a custom mode, i.e., the one seen in Figure 4.3. For the generation of diseases, a combination model was chosen that takes the set of diseases desired (those marked in green in 4.3) and a combination that satisfies a difficulty requirement of the diseases one wants to have occurred (orange ones in 4.3). In advance then the user can choose which diseases they can expect in the test. Alternatively, the test can be totally random.

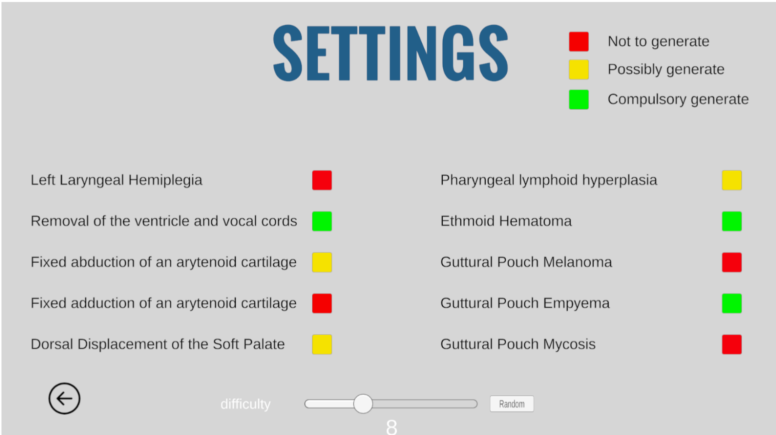

Figure 4.3: In-app generation scheme to select a custom set of diseases

After selecting the desired diseases, it is also possible to choose a kind of difficulty level, that is, different degrees of hints to make the procedure easier or more realistic.

Figure 4.4: Disease clues on the blackboard inside simulation room.

The user will then be able to keep track of their progress by checking the number of diseases they have to detect or even which ones have been generated on the blackboard in the simulation room, and as diseases are detected the corresponding clue is turned green to signal the proper identification, as in Figure 4.4.
When all is set up, once the start button is pressed, a new session is originated and the endoscopic procedure can begin.

4.1.2 Session management

All data about a session are collected and stored in an object called Session. The main goal of this object is to evaluate the user's performance during a test, carefully monitoring the user's mistakes and successes. In this way, it is possible to provide a detailed account of the user's past experiences and track the user's progress over time. To ensure data retention and portability, each session is saved in a .json file for local access or is converted to a string and sent to a server for remote access. Each session has a unique ID, a date indicating when the simulation was performed, and a mode specifying whether the package of diseases used came from a predefined set or was customized by the user. In addition, each session is assigned a final score based on the user's performance. If the score is greater than 20, it is considered "GOOD"; if it is between 10 and 20, it is rated "OK"; and if it is less than 10, it is tagged "BAD".
Within the Session object, there is a list of objects called Steps. Each Step consists of a name, a control variable that indicates whether or not the task was executed correctly, and a specific score associated with that individual Step and which will then contribute to the overall score cited above. The Steps come from the instructions provided by the Professor Bullone and represent the procedures necessary to perform an equine endoscopy correctly. These procedures are essential to ensure the safety and effectiveness of the endoscopy and to allow the user to become familiar with the correct techniques and practices during simulations. By carefully following these Steps and analyzing the results of the Sessions, users can identify their strengths and weaknesses, work to improve their skills, and monitor progress over time.
Steps common to all sessions will be listed below.

- Sedation check
  The animal must be examined in the absence of sedation, because sedation acts on laryngeal muscle control by simulating a pathological condition that does not really exist (false-positive diagnosis of laryngeal hemiplegia).

- Left nostril check

- Right nostril check

- Left guttural pouch check
- Right guttural pouch check
- Nose plugged
  During examination of the pharyngo-laryngeal cavity, it is necessary to plug the animal's nostrils for a limited period in order to induce negative pressure during inhalation to simulate what happens in high-speed exercise.
- Clean navigation
  Number indicating the collision rate by the internal probe during navigation. As critical as orienting with the walls is, a high number especially in particularly sensitive areas could annoy the horse. The result is then interpolated in a range from -5 to 5 points.
- Time elapsed
  Number showing the total time to complete the trial. Again this is interpolated between -5 and 5 points, but also takes into account the number of diseases generated.

During the simulation, it is important to examine both nostrils, for 2 reasons: the possibility of major pathologies or clinical signs affecting only one nostril, and the image distortion that is given by the angle of the endoscope, which can result in errors when evaluating cases of minor (grade 2) hemiplegia.

In addition to these Steps common to all sessions, each disease generated is itself considered as a Step, and thus added to the list. In particular, if a disease is correctly detected, its score will be added with a positive score, while a detection with an incorrect disease grade results in a zero score. If the reported disease is not present in the session, the score will be negative.

Besides the .json files that store all the steps, in case of local access a .csv file will also be created. In this file, a timestamp is recorded from the start of the test, for each step, thus making it possible to study the flow of operations performed by the user and to evaluate the efficiency and timeliness of his or her actions.
Another data that can be analyzed for the performance evaluation is the video recording of the experience using a camera inside the scene. This camera can frame the user or the monitor screen once the probe has been inserted. However, it is important to be aware that using this feature can reduce system performance, as adding another camera increases rendering times. Since there is no built-in function for creating a video, an alternative method had to be implemented, where the result is shown in Figure 4.5. The camera frames are saved as a .jpeg file and, at the end

of the session, are compressed into an .MKV video format using the FFmpeg [29] tool.

Figure 4.5: Student recorded while inserting the probe into the left nostril.

If there is ample space available on the hard drive, saving images in raw .bmp format without encoding can enhance the graphic quality. Another more efficient solution might be to use a screen capture tool, which records from the user's point of view. However, this option does not offer the possibility of having an external point of view, which could be useful in some situations.

4.2 Tutorial session

To help students who are most likely totally new to the virtual world, a tutorial has been prepared. The experience is virtually identical to the traditional one, except that here the user is guided by a synthesized voice through the procedures necessary for the proper completion of all the steps while learning the controls, possibilities, and limitations that the headset offers. The procedure involves a sequence of 10 phases in which the user gradually learns all the necessary information.

- Step 1
  The user is asked to hold the endoscope with the left hand and the probe with the right hand. This should teach the user how to handle the instruments

- Step 2
  The user is given the task of using the newly learned grip function on the nostrils, so as to facilitate the procedure, and with the other hand try to insert the probe inside the nostril.

- Step 3
  Once inserted, The user is taught how to rotate the tip of the probe inside the nasal cavity. To move to the next step, the user must try to move in all four directions.

- Step 4
  This stage explains how forward and backward movement works. He or she is then asked to move up to the larynx. As soon as the probe enters a trigger collider located at the larynx, the next step is taken.

- Step 5
  At this point, the user is asked to report the lack of vocal cords in the larynx. This is done by opening the notebook by pressing the right thumbstick.

- Step 6
  Once opened, the user is taught how to move within the notebook and select the corresponding disease.

- Step 7
  Before moving, the user is asked to plug the horse's nose to simulate a condition under stress. After four seconds of plugging, the next step is initiated.

- Step 8
  The user is then asked to use the skills learned to head for the guttural pouch. The goal is to figure out how to enter and exit the pouch.

- Step 9
  Finally, the user is asked to go back to the nostril and end the tutorial by walking out the door. The user should have learned all the features the application offers and is ready to put them into practice.

In addition, the hand models will be replaced with two joysticks, making interaction easier and more intuitive for the student which is running the tutorial. Through this method, the keys he or she needs to press will be highlighted using a blue flashing material that attracts attention at the right time. This solution, combined with the presence of a key legend on the blackboard, is designed to assist those who may be unfamiliar with specific key nomenclature. This makes it easier to learn and memorize the functions of the various keys, enabling anyone to use the device effectively and efficiently.

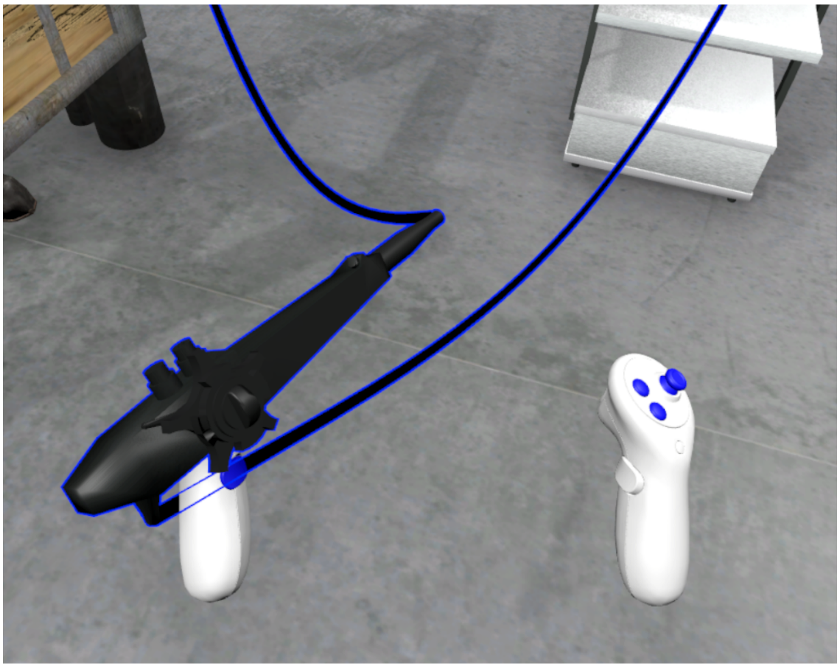

Figure 4.6: Hand view with primary, secondary, and thumbstick buttons highlighted to help user to learn faster the controls.

4.3 Endoscopy procedure

This section represents the actual simulation scene, where one virtually interacts with the room, the horse, and the various tools needed to perform the procedure. Many mechanics will be explored in this section, including the interaction with the horse and all those related to the endoscope.

4.3.1 Horse interactions

A key element of a virtual endoscopy is the virtual horse. It will react to stimuli, may show signs of annoyance if there is a bad interaction, and it will be possible to approach it to grip its nostrils to facilitate the probe insertion in its nose and then plug it to simulate a condition under stress. The mechanics of these interactions will be described next.

Annoying horse

In Unity, for the scene arrangement, the same approach adopted in the thesis that served as a ground of the present work was used, i.e. to keep the inner and outer models spatially separated. The environment was redesigned with a game design approach, by separating all the components into individual models, with their materials and prefabs, and then placing them individually in the scene. The interaction with the horse and its animations have also been changed: removed the mesh collider of the horse's muzzle, which visually generates unpleasant collisions with the probe, this has been replaced by more capsule colliders, which are simpler and primitive elements of Unity and as such are better handled by the physics engine.

Figure 4.7: Horse muzzle collider handling with multiple capsule collider.

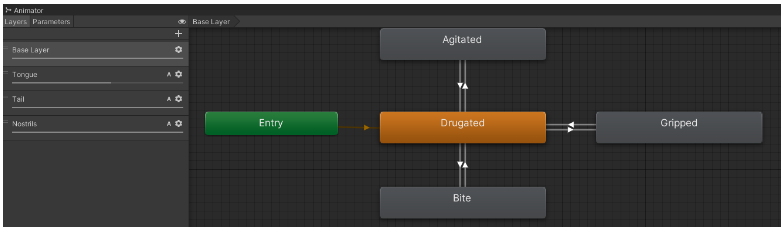

Figure 4.8: Horse animator handling various animations in additive layers

If the user with the probe annoys the horse before the probe is inserted, it will react with an animation. This is because an important part of the examination is the correct insertion of the probe inside the nostril.

Nostril grip

As specified by Prof. Bullone, proper insertion of the probe into the nostril requires that the assistant tighten the horse's nostrils so as to facilitate entry. In the application, it was chosen to have the student perform this operation directly. In order to execute this maneuver, the student must carefully approach the horse and position themselves in such a way that their left hand aligns with a designated trigger point that corresponds to the nostrils. Upon reaching the appropriate position, the student should press the Grip button located on the controller they are holding. This action triggers a dynamic gripping animation that adjusts according to the amount of pressure exerted on the button. As a result, any obstructions or colliders that may hinder the process of inserting the probe into the nostril are effectively eliminated. Once the probe has been successfully inserted into the nasal cavity, a virtual hand model persists in the visual representation of the scenario. This is done to simulate the continued presence of an assistant who is responsible for holding the horse in place throughout the duration of the procedure, ensuring that the animal remains steady and secure.

Figure 4.9: User gripping nostril to allow insertion of the probe into the nose. An animated hand appears on the nose of the horse substituting the real hand.

Nose plugging

A similar procedure to gripping is nose plugging. This is indicated during the procedure to simulate a stress test and highlight any problems that are not very prominent at rest. It is therefore required that during the session the student performs this procedure. The method employed for managing this is similar to the one seen for gripping, in fact, once the probe is inserted the user can approach the horse and if he places his hands at both nostrils, the real hands will be replaced by models that occlude the nose to generate pressure. This mechanism acts on the breath system implemented for the horse, which involves the larynx. In fact, plugging the nose gradually increases the horse's agitation, thus decreasing the time of a breathing cycle. This then temporally reduces both the inhalation and exhalation phases' time, making the succession from abduction and adduction of the arytenoid cartilages faster. Once the hands have been removed, a coroutine is performed to return to the starting condition in a smooth manner, thereby gradually calming the horse. Meanwhile, to provide additional visual feedback to the user, the horse's idle animation is sped up by a parameter that depends on how long the nose is plugged.

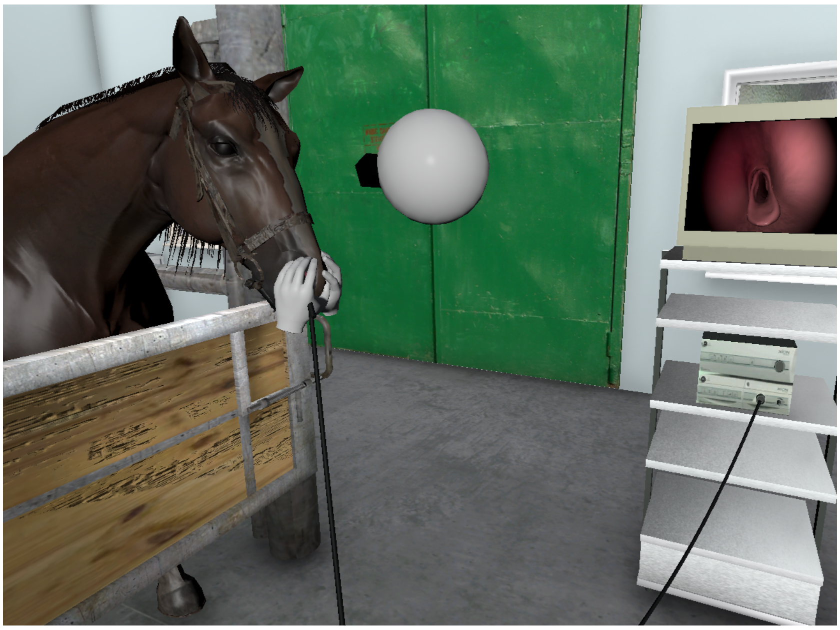

Figure 4.10: User plugging the nose to simulate under-stress condition. Two hands appear on the nose of the horse substituting the real hands.

4.3.2 Probe and endoscope

Special attention was paid to the probe. This was dealt with in two different ways before and after it was introduced into the nostril.

Probe outside

The body of the endoscope is made in Blender and was later imported into Unity. Particular importance is given to the knobs, which allow rotation of the tip of the probe on the horizontal and vertical axis, as in this way the student can orient himself once the probe is inside the horse. With the joystick of Quest 2 available, to facilitate the understanding of the student, the Touch functionality has been exploited, which allows understanding when one of the buttons is touched rather than pressed by showing the hand in the respective position (Figure 4.12).

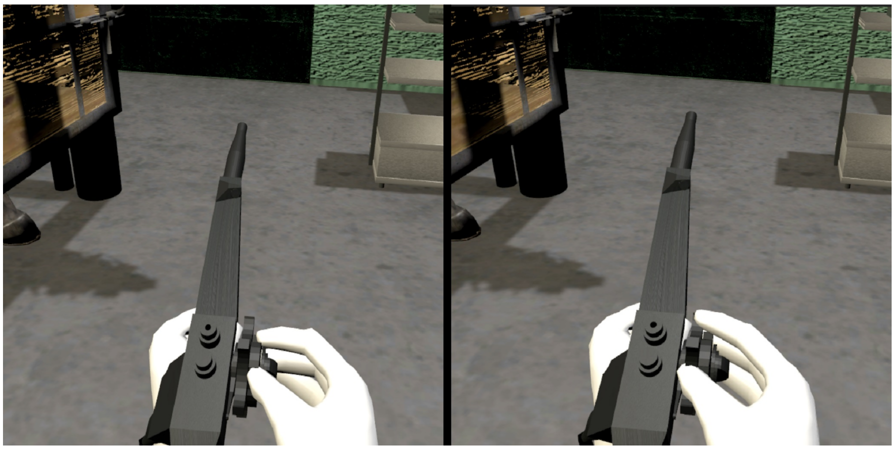

Figure 4.11: (a) Touching right-hand controller stick for little knob and (b) touching right-hand controller stick for bigger knob

The cable of the endoscope is procedurally created as a sequence of cylinders following a spline trajectory and managed by the Rope.cs class. Finally, the tip of the probe is formed by a sequence of cylinders, each with its box collider, plus a camera at the end. The output of the camera is projected onto a render texture which is then displayed on the screen. As mentioned before, the probe has a rigidbody for physical simulations, in particular for grabbing and inserting into the nose.

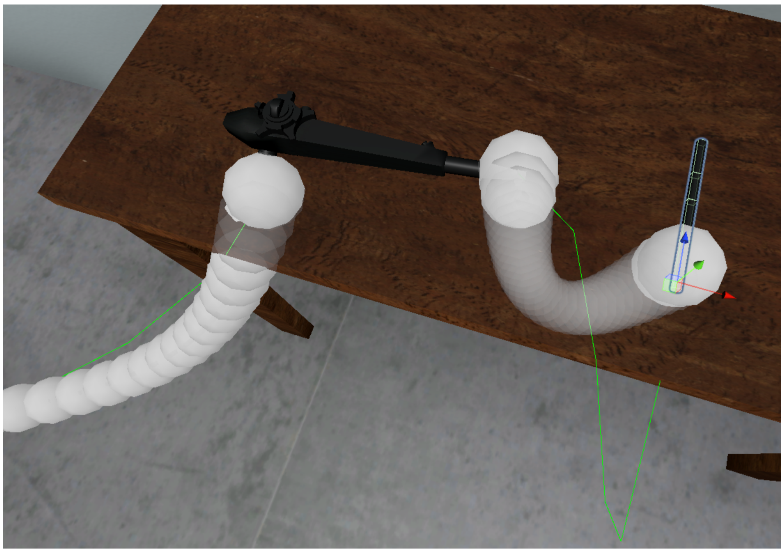

Figure 4.12: Body, cable, and tip of the endoscope. The green line represents the curve approximated as segments followed by the cable. The small spheres are the points affected by gravity that will form the bases of the cylinders from which the cable originates. The tip is subdivided into 3 different box colliders.

As far as the insertion into the nostril is concerned, the stratagem already implemented was followed. When the tip enters a trigger placed at the location of the nostril, the pieces are gradually disabled as they enter. This is because collision in Unity is a quite complex issue. By removing the pieces at the top, the probe can be inserted without any problems. As soon as a certain number of hidden pieces is reached, the probe is inserted. At this point, it is automatically repositioned, and a coroutine that makes possible the extraction after a few seconds starts. As the probe is entered, there will be a transition on the screen from the external probe camera to the internal probe camera. This is all handled by a shadergraph and thus allows for a fairly smooth switch from the external view to the internal view

Probe inside

Upon the insertion of the external probe, the internal probe becomes accessible. This design choice is primarily focused on optimizing performance, as the rendering process is known to consume a significant portion of the CPU's processing time. Consequently, having numerous active cameras within a scene can lead to a substantial drop in the overall performance, as evidenced by a decrease in frames per second (FPS).
In addition to this, the reference nostril is documented at the moment of insertion.

This allows for the internal controller to be accurately positioned within the corresponding nostril, while also providing an indication in the session that this specific task of the procedure has been completed as intended by the exam.
The movement of the internal probe is somewhat complex due to the fact that it adheres to a set of predefined constraints. The management of this probe's motion is handled by the ProbeMovement.cs script, which ensures that the internal probe operates within the specified boundaries and parameters.

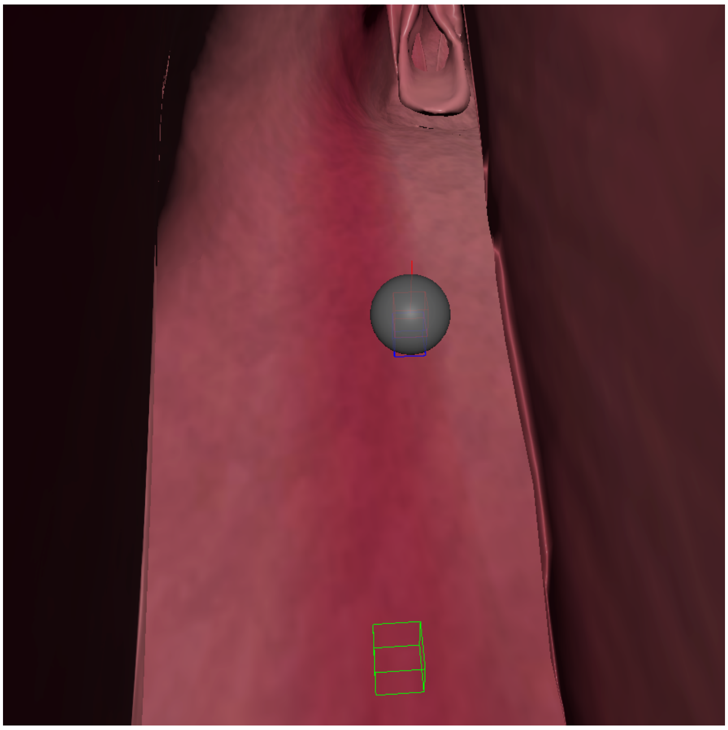

Figure 4.13: Internal probe design. Single sphere that can rotate around a pivot, itself or parallax and move in the direction of its parent. The blue wirecube indicates the position of the pivot, the green one of the root node

The internal model of the probe (Figure 4.13) consists of a root node that retains information about forward movement since the motion does not follow the direction of the point of view, but instead follows the direction of the cable. As a child of the root node, there is the pivot, the element around which the rotation of the tip occurs. Finally, the tip itself can be founded, represented as a sphere, which is also capable of rotation. The camera is controlled by an external empty object, which has a script associated with it that allows it to follow the sphere as it moves. This solution was adopted to smooth the transitions caused by sudden rotations due to collisions with surfaces.

To analyze the system in an organized way, it is possible to divide it into sections, each pointing to a type of movement that can be made during the experience, i.e., frontal movement, backward movement, scripted movement, rotational movement, or movement as a result of collisions.

- Forward movement
  Controlled by the right-hand trigger or from the keyboard by a possible assistant, the sphere proceeds along the direction set by the root node and its advancing is blocked in case of frontal collisions with walls. The motion is designed to emulate the behavior of a flexible cable being advanced within a tight passage: the cable adapts to the walls and changes direction while the operator simply pushes or retracts the cable. The cable has a length parameter that limits its travel. This limit was introduced mainly to prevent the cable from going over the trachea area and into the void.

- Backward movement
  The backward movement is controlled by the left-hand trigger or, again, by keyboard commands provided by a possible assistant. During frontal forward movement or following a collision, the position and rotation of the sphere are sampled and pushed into two stacks. When the cable is withdrawn, the movement proceeds to the previous element of the stack and so on, until the stack is completely emptied, which corresponds to the entry point in the nostril.

- Scripted movement
  During the experience, such as in the tutorial and, in particular, when entering or exiting a guttural pouch, it was necessary to disable the standard motion in order to handle it differently. In this context, a boolean variable is used which, when set to true, prevents the script from running as normal.
  To enter a guttural pouch in reality, the use of a guide is required, which is a strong but thin cable that emerges from the end of the probe and is inserted into the ostia until it enters the pouch. Next, the probe follows the path traced by the guide, which is finally retracted. In the application, however, it was not necessary to implement this mechanism, so the probe is simply brought closer to the ostia for insertion, as shown in Figure 4.15.
  The entry into a guttural pouch is divided into three parts: an entrance, equipped with a trigger collider; the conduit, described by a Bezier curve; and, finally, the exit, also with a trigger collider. The probe interacts with the trigger at the entry, which enables scripted movement. At this point, the velocity is checked: if it is positive, it indicates that the probe is entering the pouch; if it is negative, it means that it is returning to the nasopharyngeal cavity and normal movement can be restored. If the probe is entering the

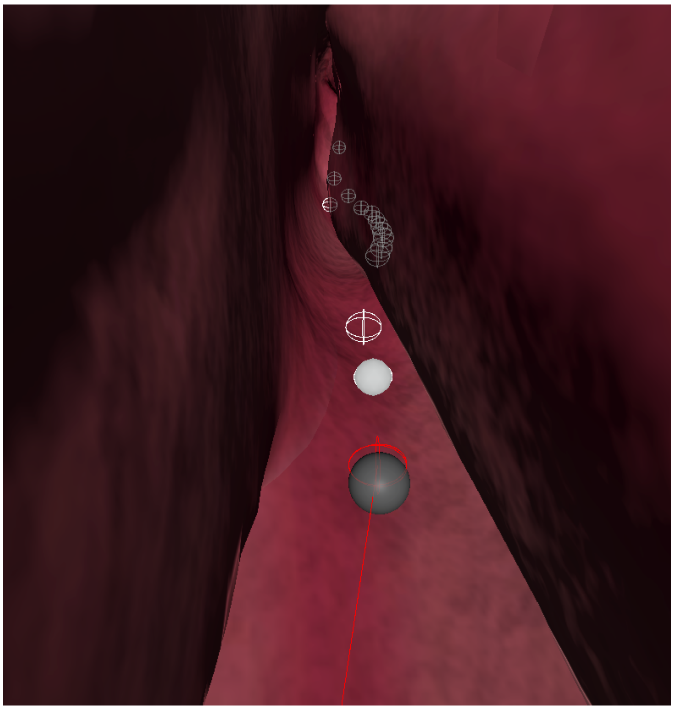

Figure 4.14: The red wiresphere shows the sampled points during the movement. The white sphere displays the last reference point for backward wire movement.

pouch, along the conduit it follows a trajectory defined by a Bezier curve until it reaches the exit, where it again encounters a trigger. At this stage, velocity is sampled to determine the direction of motion. Such a solution was chosen because the conduit has a very small diameter and the sphere would not be able to adequately handle collisions under normal conditions.

- Rotation around pivot and itself
  Using the knobs on the base of the endoscope, you can flex the probe tip in the various axes.
  To achieve a realistic effect in the simulation, the sphere follows a double rotation mechanism: one rotation around its own axis and another rotation along an external axis. This combination of movements simulates the idea that the probe is composed of several flexible parts that can bend and move independently.
  Rotation along the external axis is accomplished by turning a pivot, located in the center of the sphere. This rotation is clamped between a minimum and maximum angle, which in reality correspond to about -60 and 60 degrees. The rotation factor, which ranges from -1 to 1, is achieved by manipulating a knob using the stick or the controller or the primary/secondary buttons.

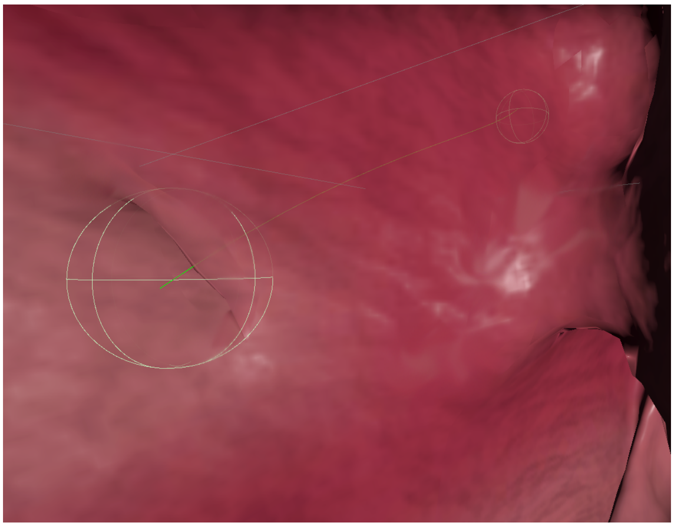

Figure 4.15: The first green wiresphere is the trigger collider at the entrance, while the second is the exit one. The green curve is the Bezier curve for the movement inside the conduit

Figure 4.16: Rotation of the tip of a real endoscope

However, this rotation is further clamped by the constraints imposed by collisions between objects in the simulation.

- Rotation around parallax
  The probe tip is able to rotate around its own axis, either clockwise or counterclockwise. In a real-world situation, this rotation is usually controlled by an assistant who maneuvers the cable at nostril level to ensure optimal view orientation. In the simulation, this mechanism is reproduced by rotation around the frontal axis of the parent pivot.

- Collisions
  As mentioned earlier, to move inside the nasal cavity it is necessary to lean against the nasal mucosa and follow that trajectory. For example, for an analysis of the right guttural pouch, during the examination it is good to keep as much as possible to the right wall to be driven to the respective ostia. For collision management, a series of raycasts are fired in the various directions in search of a collider.

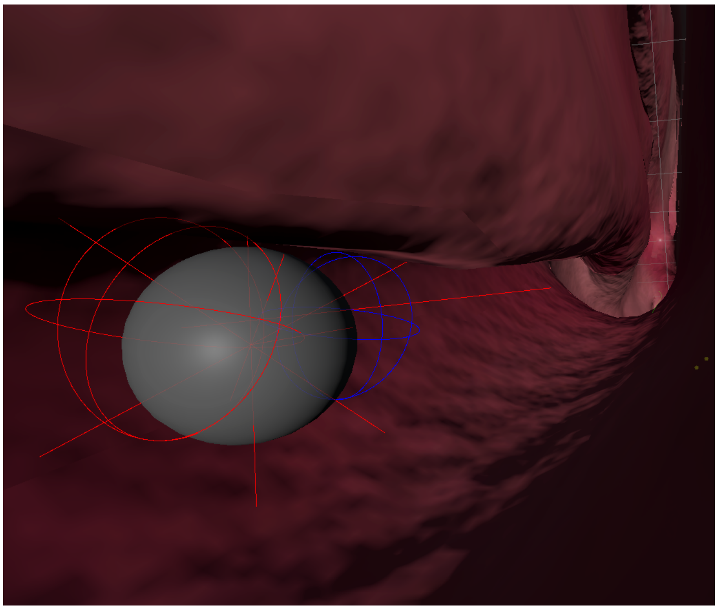

Figure 4.17: The red lines are the raycasts fired in the various directions for collisions

If a collider is detected, first the respective rotation limit discussed above is set to zero, so that rotation in that direction is prevented and thus passes through the wall. This is done for all raycasts, then at the end the angle of incidence between the collision normal and the forward of the tip is computed. If this angle is less than 15 degrees, the collision is considered to be frontal, and the tip is incapacitated to move forward. Otherwise, the new direction is calculated by taking the tangent of the collision (the projection of the tip forward vector onto the surface of the hit object, using the surface normal as the projection plane). Then, the sphere is oriented along that direction, and the pivot and root node are reconstructed accordingly so that they are always behind the point. In this way, the motion can continue in the new direction.

4.3.3 Disease detection

A crucial component of the simulations is the ability to correctly detect and report the presence of any disease. To facilitate this process, a virtual notebook was created that allows the student to select the disease currently displayed on the monitor display. The notebook can be opened at any time during the simulation, and upon opening, a screenshot is captured from the probe camera. This image is then saved on the left page of the notebook for easy visualization and reference during disease selection. After viewing the screenshot, the user can select from

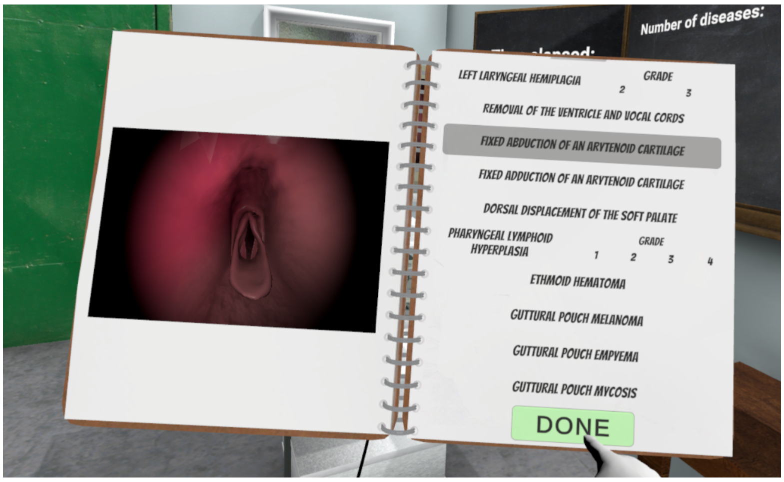

Figure 4.18: Notebook inside the simulation. On the left there is the screenshot taken by the user, on the right the list of the diseases that can be selected

the list of available diseases, using the thumbstick or by interacting directly with the finger, the one they believe they have identified and confirm their choice. The identification process requires establishing whether a particular disease is currently captured by the camera. To implement this functionality, each disease-generated element was equipped with a trigger collider at the time of its creation, in case it did not already have a mesh collider. For each disease, a list containing all these elements and their detection status is created and stored.
The first step in determining whether a disease is framed by the camera is to check whether its trigger collider is within the camera frustum. The camera frustum is that portion of three-dimensional space that is projected onto the two-dimensional

surface of the camera screen. In other words, it represents the area visible by the camera. To do this, it is necessary to examine the list of trigger colliders that

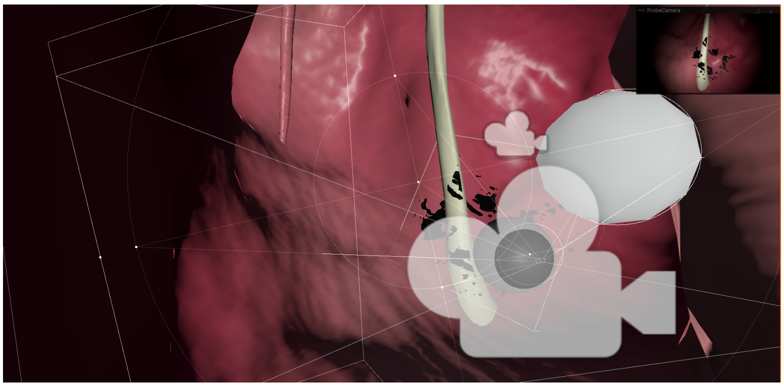

Figure 4.19: Probe camera frustum (white truncated pyramid with a four-sided base) and in green the melanoma trigger collider for detection

make up each disease and determine whether these are partially or fully included in the frustum. To determine whether a 3D object (represented by its bounding box) is visible within the camera frustum, two specific functions of the Unity library are used. The first function calculates the six planes of the camera frustum (projection plane, near plane, far plane and four side planes) and saves them in an array of Plane objects. Next, the TestPlanesAABB function is used to check whether the bounding box of the object intersects any of the camera frustum planes saved previously in the array. If the object is not within the frustum, it can be immediately concluded that it is not visible and, consequently, a false report is given. However, in the case where the object is actually in the frustum, further checks must be performed. This is because the object could be inside the frustum but be hidden behind another object and, therefore, not be directly visible. In this situation, additional checks must be performed to determine whether or not the object is actually visible, taking into account the other objects in the scene and their relative position to the camera and the object of interest. An effective method to check occluded objects is to use a raycast and a spherecast. Initially, a raycast is thrown from the camera toward (the center of) the object of interest. If the raycast intercepts an occluding object, that is, a non-trigger object, before reaching the object in question, it can be concluded that the object is not directly visible. Next, a spherecast is shot in the front direction of the camera and the same mechanism used for the raycast is applied. This additional step is necessary because some objects, such as the hematoma, may not have their center positioned at the correct location, making it insufficient to use a single raycast to determine visibility. Finally, the result of the logical OR between the information obtained from the two checks is returned, indicating whether the object is visible from the

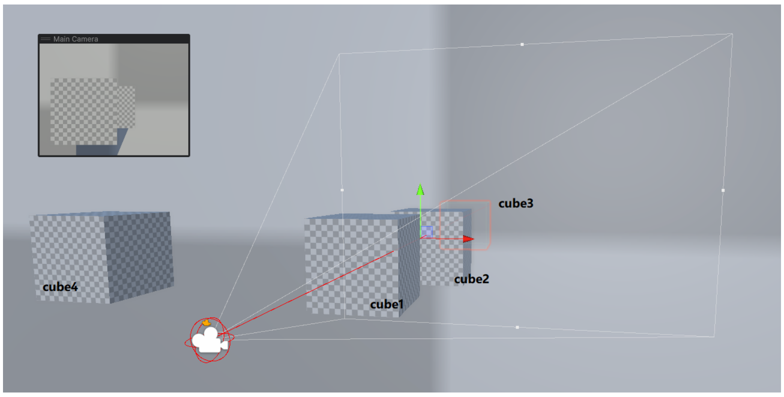

Figure 4.20: Cube3 is in frustum but it is occluded by another object. Cube 4 is out of it.

center, frontally visible, or occluded by other elements in the scene.

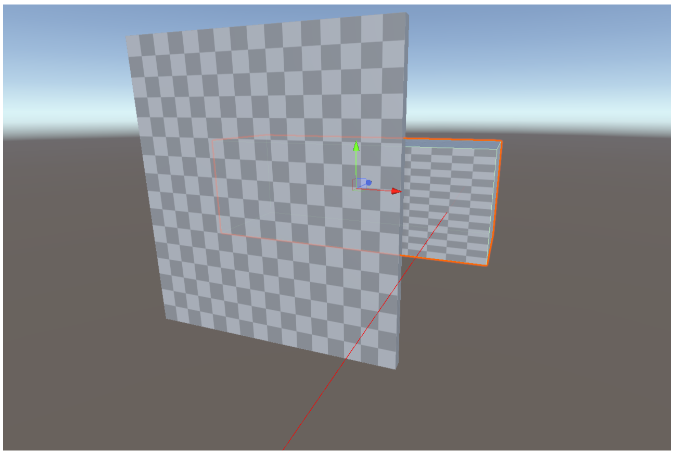

Figure 4.21: Object that is not center visible but only frontally visible can be detected by a spherecast

The flowchart of this operation will be shown below to make the sequence as clear as possible.
At the end of the simulation, a partial score will be calculated for each disease generated based on the number of items identified for that disease.

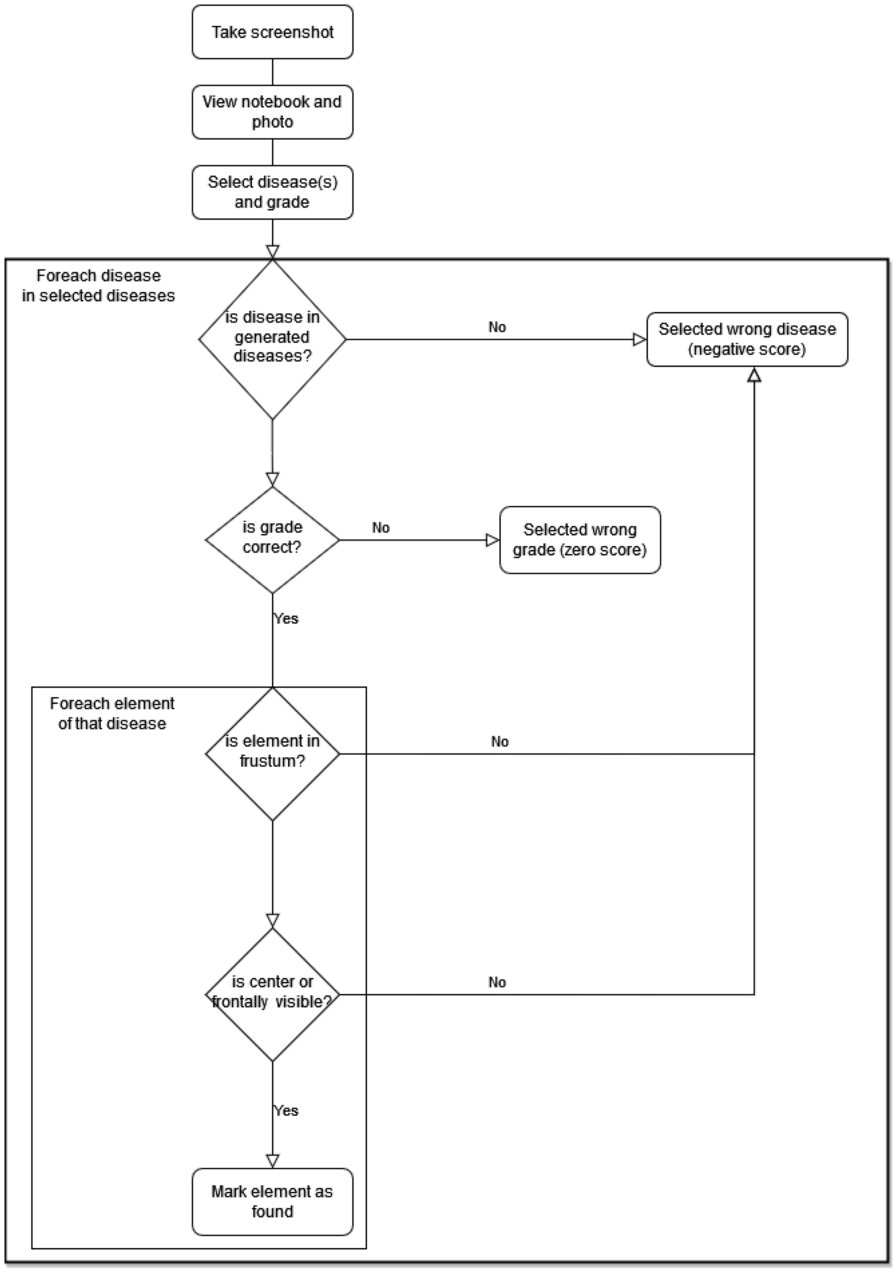

Figure 4.22: Flowchart representing the disease identification algorithm

Chapter 5

Experiments and results

5.1 Introduction

This chapter presents the experiments conducted in order to evaluate the effectiveness and usefulness of the project proposed as part of the thesis. The protocol is to provide both groups of students with the needed theoretical material and then compare the results obtained through a practical exercise in the laboratory using VR for the first group and standard materials for the second one. Finally, the students made an assessment test on real horses, filling in for all the conditions an evaluation test of the experiences in order to draw conclusions about the potential positive implications of the project on student preparation. The in-depth description of the procedure is described next, with a schematization in Figure 5.1.

5.2 Methodology

The experiments described in this chapter were conducted by students from the Department of Veterinary Science of the University of Turin, under the supervision of Professor Michela Bullone, as part of their first-course attendance.
In total, seven students participated in the experiments, divided into two groups: a team of five students who carried out the VR laboratory and a control group consisting of the remaining two students. At the end of the experiments, both groups conducted a practical examination on real horses. The students who performed the exercise in VR were paired with an assistant who supported the virtual endoscopy, following the students' instructions regarding forward, backward movements and clockwise or anticlockwise rotations performed on the computer and not through the controllers. This choice was made to simulate the collaboration between student and assistant during an in vivo endoscopic examination and eventually help the student during the simulation.

Before the experiments began, Professor Bullone selected three specific diseases for each student, without informing them of either the number of diseases or the specific conditions they might encounter during the examination. This was done in order to provide maximum stimulation for the students' research and attention during the experiments, without influencing them.

5.2.1 Partecipants

Five students were involved in the experimental group that used immersive VR and two students in the control group. Among the participants in the experimental group, 3 were girls and 2 were boys, with an age between 22 and 25 years old. In the control group, however, there was one boy and one girl, aged 22 and 23.
Before taking part in the experiment, none of the students had ever had experience with VR. In addition, only one student had previously been involved in an in vivo endoscopy examination but had never personally inserted the probe.
All participants voluntarily chose to join the experience proposed by Professor Bullone. During the experiments, the students were supervised and supported by Francesco Bonini, Professor Michela Bullone, one of her colleagues, and correlators Filippo Gabriele Pratticò and Edoardo Battegazzorre.

5.2.2 Materials

The experiments were conducted in a conference room courtesy of the Polytechnic University of Turin. The testing environment consisted of two laptops connected to two Oculus Quest 2 headsets for simulations and two other laptops dedicated to questionnaire completion. With this configuration, it was possible to simultaneously monitor two students during their tests, recording the sessions while the other participants filled out the questionnaires.
The questionnaires were designed by the thesis correlators and are divided into several sections:

- Pre-training questions
  Self-efficacy

- Post-training questions
  Self-efficacy, cognitive load, attention, relevance, confidence, satisfaction

- User Experience Questionnaire (UEQ)
  Attractiveness, quality, efficiency, usefulness, input, fidelity, System Usability Scale (SUS)

- Post Real Assessment questions
  Learning awareness, immersion/presence, cognitive load, Post-simulation Health Self-assessment [SSQ] (only in case of discomfort)
- Comments (2 positive aspects, 2 negative aspects)

During each session, data were collected in two different file formats:

- A file containing the timeline of user operations, to analyze the order of actions performed and the time taken to complete them.
- A file related to the session, which records procedures performed correctly or incorrectly and diseases detected, along with their scores.

5.2.3 Procedure

- Theoretical lecture with students:
  1. Students attended a theoretical lecture regarding the endoscopy procedure, studying the endoscopic equipment and the anatomy of the horse.
- Pre-experiment setup:
  1. Students completed the pre-training questionnaire at home, which included a quiz of theoretical and practical questions.
- Participant instructions:
  1. Participants were welcomed and guided to the designated computer.
  2. Instructions on the use and rules of the Oculus Quest were provided.
- Tutorial procedure:
  1. Before the experimental procedure began, the students followed a tutorial to familiarize themselves with the controls and mechanics of the simulation (probe insertion, movement within the nose, notebook opening, etc.). No data were collected during this phase.
- Experimental procedure:
  1. The session with the respective diseases was selected and generated.
  2. The student was allowed to act freely.
  3. During the test, if the student was unsure how to proceed, they received suggestions from the attending assistant.
  4. The student decided at their own discretion when to end the procedure.

- Post-experiment:
  1. The participant was asked to complete the post-training questionnaire.
  2. A new student started the procedure.
- Procedure on a real horse:
  1. Students performed an endoscopy on a real horse.
  2. Students filled in a post-assessment questionnaire.

Schematically we can represent it as in Figure 5.1.

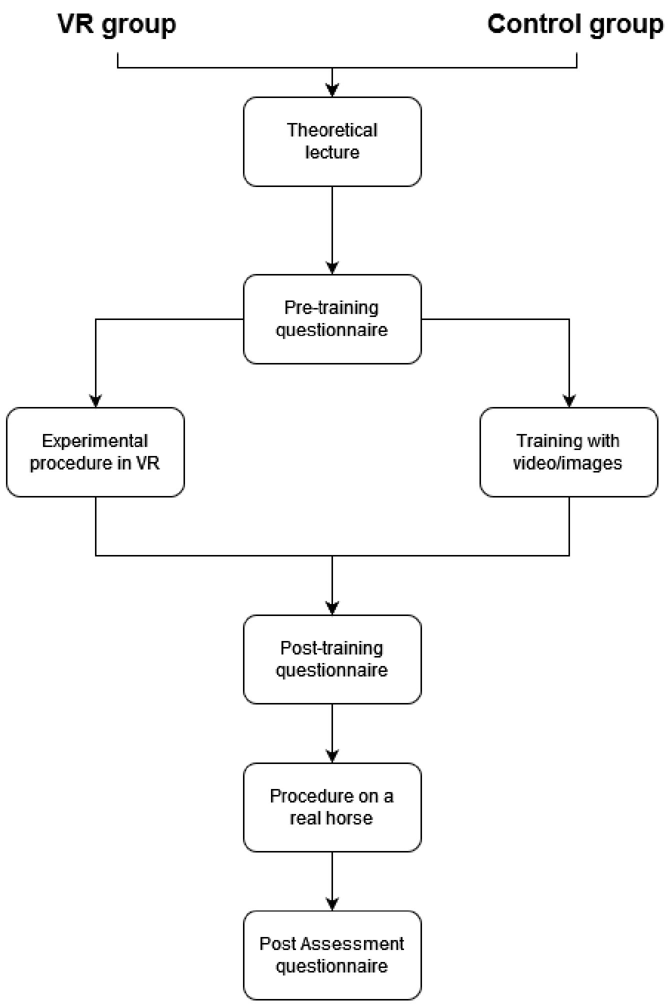

Figure 5.1: Flowchart representing the different training paths for the two groups.

5.2.4 Data analysis

Data were collected in an excel file and processed, producing plots for visualization and analysis.
The statistical methods used are the average, the standard deviation to measure the variability of the data, and the p-value, which helps to assess the reliability of an experimental result, indicating the probability of obtaining a result at least equal to that observed. These considerations were made for the VR and control groups, comparing them to see what the strengths of one and the other are.

The software used for analysis is Microsoft Excel, with the support of an add-on for p-value calculation.

5.3 Results

5.3.1 Simulation statistics

Personal and demographic data

The findings of the population analysis show that the mean age of the VR group is 22.8 years, a value virtually identical to the 22.5 years of the control group.

Among all the students analyzed, two belonging to the control group are from a Scientific High School, while in the VR group there are three students from a Scientific High School, one from a Technical Institute, and one with a high school diploma as a qualification.

Questionnaire results

- Pre-training self-efficacy
  For both groups, the average self-efficacy is moderate at 2.8 out of 5. Looking at a p-value of 0.571, it can be said that there are no statistically significant differences between the ratings of participants who used VR and those in the control group.

- Post-training self-efficacy
  The average post-training self-efficacy of the experimental group is 2.9, while the average of the control group is 3.4: this suggests that participants in the control group had slightly higher self-efficacy than those in the experimental group. However, by observing the p-value of 0.190, it can be said that there are no statistically significant differences between the two groups.

- Intrinsic cognitive load
  Intrinsic cognitive load refers to the amount of mental effort required to understand a given topic or task. By analyzing the p-value of 0.381, it can be determined that there is no significant difference between the two groups.
- Extrinsic cognitive load
  The extrinsic cognitive load takes into account anything that contributes to cognitive load but does not make up the experience, such as a font that is too small that makes instructions unreadable, or an external noise that is distracting the user. As in the previous case, there is no significant difference between the two groups in this field.
- Germane cognitive load
  The cognitive load germane refers to the mental effort required to actively process information and connect it with past knowledge. Again, there is no significant difference between the two groups.
- Instructional Materials Motivation Survey (IMMS)
  In this part of the questionnaire, effects on attention, relevance, confidence, and satisfaction were assessed. While the field results are basically equivalent, the one on attention is particularly remarkable, with an average of 4.6 for the VR group versus 3.8 for the control group. But of particular importance is the p-value of 0.095, indicating that the observed difference is statistically significant (according to the established level of significance).
- UEQ
  Looking at the various parameters considered by the UEQ among attractiveness, quality, efficiency, and usefulness, none of them had any notable results. Except for quality, on the other occasions, the average of the VR group is 0.4-0.5 out of 9 higher than that of the control group. However, the p-value found no significant difference between the two groups.
- Usability
  This part of the questionnaire relates only to the VR group and thus to the application itself. The comfort of using the input commands has an average of 3.8 out of 5, considered by students to be somewhere between satisfactory and very satisfactory. Meanwhile, the level of fidelity rises to 4, again finding the students' opinion between satisfactory and very satisfactory.
  The SUS score of 80 points indicates that the system is considered easy to use by most users. In general, a SUS score above 68 is considered a good score, while a score over 80 is considered excellent.
- Post real assessment questions
  The difference between the two averages is 1.5, with 5.6 for VR and 7.1 for

the control group: this indicates that the post-assessment cognitive load of the experimental group was lower than that of the control group.
The p-value is 0.095, indicating that the observed difference is considered significant and that the use of VR had a meaningful impact on the participants' perceived cognitive load compared with the control group.
Moreover, the average of the experimental group's conception of the complexity of the teaching module is 5.6, while the control group's average is 8.5: this indicates that participants in the control group reported a perception of greater complexity, and this difference is evidenced by a significant p-value of 0.095.
Furthermore, the control group reported a higher level of extrinsic motivation than those in the experimental group.

Regarding the pre-post training and post-assessment test scores, there were no significant variations. The only remarkable fact worth considering is that in the post-assessment, the VR group had a higher average of 10%, i.e., 0.6 versus 0.5 with a scale ranging from 0 to 1.

Objective results

Analyzing the data provided by the simulation, it can be seen that the average duration of a virtual endoscopy session is 22 minutes, with a minimum of 18 and a maximum of 30 minutes. In addition to this, it is possible to give an estimate of the success rate of disease detection during testing, as shown in Figures 5.2.

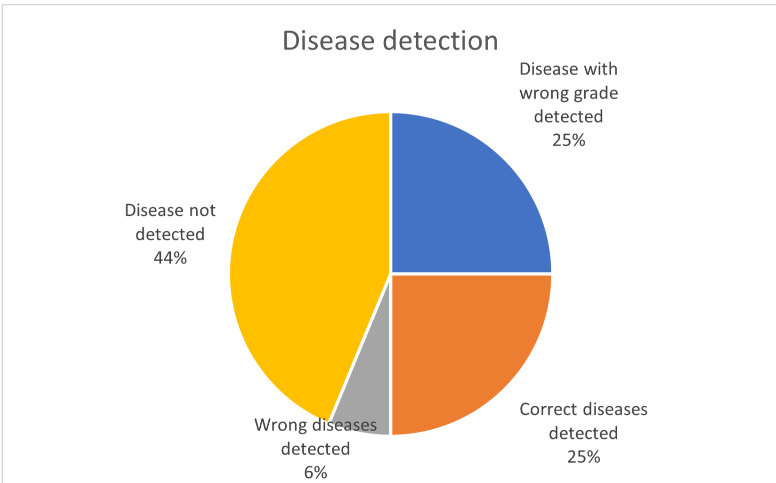

Figure 5.2: VR group session evaluations regarding diseases correctly detected or not in an average session.

5.3.2 Interpretation of the results

Among all the data collected, it is possible to draw some conclusions. The key points of the success of VR concern the cognitive load both during the training and the test with the real horse. In particular, it is possible to say that the use of VR had a positive effect on the concentration level of the participants during the training. This suggests that VR could be a useful tool for improving the ability to maintain attention while performing complex tasks. Post-assessment cognitive load was also lower for the VR group, and one possible explanation could be that VR provided participants with a more engaging and interactive learning experience, which made them more confident and allowed them to deal with the real procedure more efficiently and with less cognitive effort, as visible in Figure 5.3 and Figure 5.4.

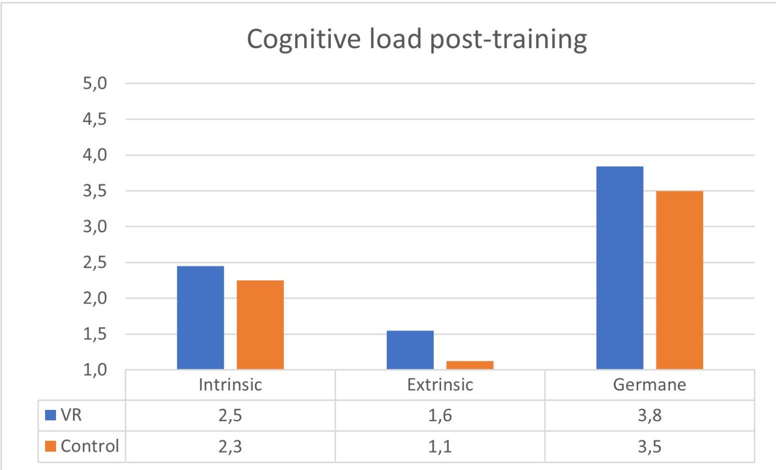

Figure 5.3: Cognitive load post-training comparisons between the two groups.

However, it also appeared that the students in VR felt after the experience that they had partially acquired the information useful for identifying any pathologies/dysfunctions during equine endoscopy. This might suggest that the use of VR did not provide participants with sufficient knowledge to identify conditions in equine endoscopy. There may be several reasons why the average for the VR group was lower, for example, the quality of the virtual simulation may not have been realistic or engaging enough, or participants may not have received adequate training or support while using VR to gain the necessary knowledge.
Finally looking at the enjoyment ratings such as SUS, which is very high, it can be said that the experience was overall appreciated by the students.

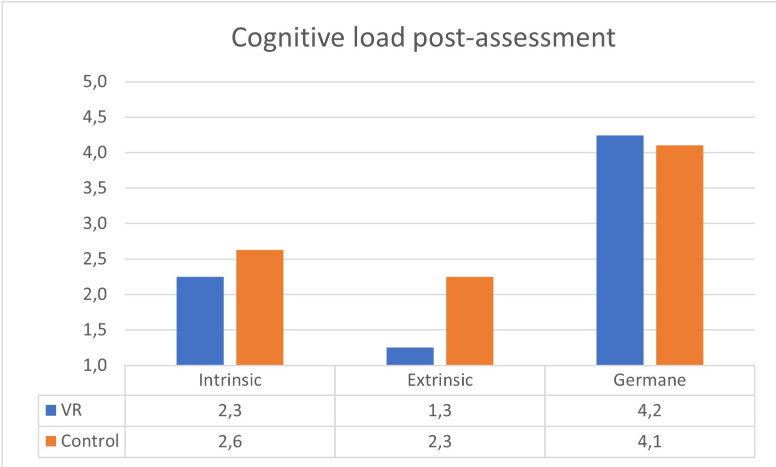

Figure 5.4: Cognitive load post-assessment comparisons between the two groups.

5.3.3 Students' comments

There was also a comments section within the questionnaire, and a summary of the considerations can be provided to give insights for the future applications. The comments highlight the usefulness of the VR experience in preparing them for endoscopy on a real horse. However, they suggest that the introduction of a theory session on conditions observable by endoscopy and the opportunity to review photos and videos of different conditions could further enrich the VR experience and improve the recognition of conditions both in VR and in vivo. Students appreciated the realistic reproduction of the environment and the opportunity to practice without the anxiety and fear of making mistakes that are present in live tests. Some suggestions include adjusting the breathing rate and laryngeal cartilage movements based on the actions performed, as well as improving the initial guidance and navigation within the VR experience. Overall, the VR experience was evaluated positively and found to be educationally useful for students.

5.3.4 Conclusion

In conclusion, this study provides valuable insights into the effectiveness of VR as a training tool in comparison to traditional techniques. However, it is important to view these results with some caution, given the limited number of tests available.

Chapter 6

Conclusion

The development of this project is based on the realization of the software in the Unity engine, achieving a system that works according to the given requirements requested by Professor Bullone. This system allows teachers to provide an immersive experience for students by deflecting from what is the traditional method, respecting the 3Rs principle.

The developed VR application lays the foundation for an even more extensive simulation system for equine endoscopy training. It can be extended in countless ways, such as adding new conditions to detect or introducing different types of endoscopic procedures. The current simulation provides a cost-effective and safe method for veterinarians and students to practice equine endoscopy skills. With further refinements, this VR simulation could provide a comprehensive training tool that allows trainees to experience a wide range of conditions and complications in a risk-free virtual environment. While still limited in scope, this simulation highlights the potential of VR technologies for veterinary education and training. Future work could explore applications for other types of veterinary procedures, diagnostics, or treatments.

In conclusion, this thesis presents a novel VR simulation system for equine endoscopy training with good results obtained from testing with students and promising prospects for expansion and further development. With further advancement, such simulation technologies may eventually become invaluable resources for delivering safe yet comprehensive procedural training to veterinarians and veterinary students.

List of Tables

List of Figures

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