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A Novel Computational Framework for Visual Snow Syndrome

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ABSTRACT Visual Snow Syndrome (VSS) is a neurological condition that impairs the perceived image by causing the appearance of numerous constantly flickering dots, similar to those seen on a television screen that does not receive the antenna signal properly. This article presents two innovative applications using emerging technologies to help people suffering from VSS. One is based on Augmented and Virtual Reality to simulate the visual perception experienced by people affected by such syndrome in real time on the image sequence acquired by a smartphone's camera. The other is based on a web platform based on a Virtual Reality engine, designed to create exercises parametrically to improve the user experience and the usability of an experimental therapy that aims to alleviate the syndrome's symptoms. We present the architecture of the two systems, which is characterised by a very simple yet very effective approach and use, as documented by the comments made by users. The results of an evaluation questionnaire submitted to volunteers who tested and scored the mobile App and eventually expressed opinions and suggestions are reported. The questionnaire results show users' positive appreciation, as they outline in their comments how important it is for patients to have simulation tools that allow them to better explain their pathologies.

INDEX TERMS Augmented Reality, Human Computer Interaction, Unity, Visual Snow Syndrome, Virtual Reality

I. INTRODUCTION

VISUAL Snow Syndrome (VSS) is a rare neurological disorder that causes disturbed visual perception full of visual noise, similar to the snow effect observed on an old television set that is not tuned correctly. The intensity of the visual noise can vary depending on the severity of the syndrome and is often accompanied by other visual disturbances such as Eye Floaters or Aura Migraine.

The exact origin of this condition is still debated, but researchers agree that a neurological disorder causes it. Experimental research is underway to find therapies that can benefit these people. Although this syndrome has a fairly relative incidence (at most, it affects 2% of the population), it has several implications for Virtual and Augmented Reality, as it concerns the sphere of vision. This paper presents two innovative applications that use Virtual and Augmented Reality to provide important support to people with VSS. The first is an Android application that aims to simulate the visual perception experienced by people with VSS in real-time using the image sequence acquired by a smartphone's camera. Applications are often developed to reduce the discomfort of a disease or improve the quality of life of those suffering from it. With this application, we want to show that it is also useful to focus on the development of applications that simulate pathologies and the problems they cause. This will help sufferers better explain their problems to doctors, friends, and family members and help non-sufferers better understand the discomfort these people experience on a daily basis. It will also raise awareness in the community.

The second application aims to improve the accessibility of some exercises in an experimental rehabilitation program developed by the Visual Snow Initiative (VSI). This nonprofit association seeks to help people with this syndrome. While VSI's exercises are based on a series of videos that can be downloaded, the implemented web application enables the production of videos whose effect varies parametrically.

To validate the Android application, an analysis of a questionnaire administered to some volunteer users who scored the App and eventually expressed opinions and suggestions about it is presented.

This paper is structured as follows: in Section II, we present some relevant publications that summarize the current status of the research in the field; in Section III, we describe the architecture of the system implemented; in Section IV the features and the characteristics of the App are discussed; Section V presents an improvement for the Web environment related to the vision of the videos provided by Visual Snow Initiative (VSI). Section VI illustrates the composition of the questionnaire, the presented questions, their purposes, and the statistical description of the responses. The description also focuses on the methods used to collect the data and how the anonymity and privacy of the research participants were ensured. The users' responses, feedback, and suggestions for possible improvements are presented. In Section VII, the results of the responses that were collected are analysed. Section VIII concludes this paper by making final remarks on the results obtained and possible future developments of the technologies presented.

II. RELATED WORKS

Visual Snow Syndrome (VSS) is a condition that, to date, is still the subject of considerable research to understand its origin and explore possible therapies to bring benefit to those affected by it [1].

Among the various foundations and associations studying VSS, the Visual Snow Initiative[1] actively researches new solutions [2] such as neuro-optometric visual rehabilitation therapy [3] or Mindfulness-Based Cognitive Therapy (MBCT) [4].

There are also other associations dealing with the problem of VSS, such as Eye on Vision[2] which raises funds for research and public awareness of the problem [5] or the Migraine Trust association[3].

Scientific research suggests that the origin of this issue is at neurological level [6]. Vision disturbed by the snow effect is present throughout the day and can be observed even when the eyelids are closed; the effect is observed independently during the day and at night [7]. Quite often VSS is present in people who also have other problems often associated with vision such as Eye Floaters [8], Palinopsia [9], and Photophobia [10], in some cases there is a correlation with migraine [11]. Studies suggest that Visual Snow sufferers often indicate states of increased anxiety and consequent preoccupation with their visual condition. This state of anxiety and constant observation of one's visual quality might accentuate the ability to perceive moving bodies, as in the case of Eye Floater, or other defects that might go unnoticed under normal conditions [12].

The use of modern technologies such as, for example, Virtual Reality and Augmented Reality can help by providing simulation capabilities that were not possible until a few years ago [13]–[16]. This is partly due to the significant increase in computational power that modern processors can make available to users [17], not only regarding devices that can be installed within desktop systems but also in mobile platforms such as smartphones and tablets [18]. With modern smartphones, it is possible to realise complex and detailed scenes that can be viewed in real-time, even in stereoscopic mode, thanks to the use of special lenses that allow you to see three-dimensional images and that can be attached to your devices [19]. It is possible to perform calculations with very low latency using only the computation offered by the device's GPU [18]. The ability to perform calculations quickly with low latency is crucial to simulating the visual perception of VSS sufferers and making the experience as realistic as possible.

Two software are presented in this paper. The first takes advantage of Augmented Reality, a technology that can be implemented inexpensively and is easily accessible to the public, as it can be used even with a typical Android smartphone [20] and that after capturing the rear camera image applies certain filters that simulate the effect of VSS. The COVID-19 pandemic that we recently overcame showed that being ready with appropriate digital technologies is crucial in the modern world [21]–[23], as well as the development of telemedicine [24] and telerehabilitation [25].

The second application aims to improve usability and user experience, particularly for people without fast and reliable Internet connections. To date, the average speed of the network connection that users have available in their homes is the result of investments and upgrades [26], [27]. However, although in Europe and America, the average speed of Internet connections is high, there are areas in the world where the Internet connection has a much lower speed [28]–[30] and therefore may benefit from downloading less data to access web content. In addition, the possibility of modifying the exercise content by acting on a programming code allows the visual content to be adapted dynamically. Nowadays, it is possible to develop Virtual Reality applications that can be delivered via web technologies, such as WebGL [31], which allows using a web browser to access the applications produced. Furthermore, these applications can be placed in docker containers to guarantee scalability according to the number of users who will use them simultaneously [32], [33].

III. THE ARCHITECTURE OF THE PROPOSED SYSTEM

In this section, the architecture of the applications are described. The architecture of the mobile application is shown in Figure 1. As can be seen from the image, users must first download the application to their smartphone from the official Google Play Store. The application does not require authentication, and you do not need to register an account to use it. Once opened, the user can select the desired Visual Snow noise simulation level. This way they can show another person, such as a doctor or friend, how they see the world. The person looking at the phone screen will see the image captured by the device's camera with the noise that was selected and will be able to better understand how the VSS user perceives the world. The application does not access user data and does not require an internet connection. It requires access to the camera. The complete application description can be found in Section IV.

To facilitate the accessibility of experimental therapeutic exercises, a web environment is proposed that uses techniques

[1]https://www.visualsnowinitiative.org
[2]https://www.eyeonvision.org/
[3]https://migrainetrust.org/

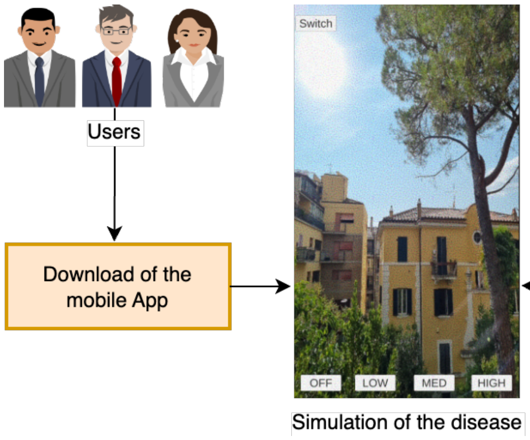

FIGURE 1. Architecture of the mobile application

that can enable even people who do not have a fast Internet connection to access these exercises effectively. At the heart of this system is a web server that hosts the web pages containing the exercises to be performed, these exercises in the original version are videos of about 20 minutes containing video noise to be viewed by users. The preparation of these videos takes a considerable amount of time by the operators. Once the noise's patterns have been defined the videos are recorded and encoded. The main problem is that the compression of videos of this type is very complex. Modern codecs work by optimising the pixel matrix of the screen, identifying similarities among different frames. In this case, the noise is completely random and unpredictable, frustrating the possibility of achieving similarity between successive frames. For this reason, videos are very large, and a fast Internet connection is required to view them without problems. To overcome this problem, a web platform was developed using WebGL technology. This technology allows applications that use the GPU to run within a web browser without the need to install add-ons such as browser extensions or plugins. The downloading of these videos has been replaced with the streaming of a JavaScript code that generates the noise effect in real-time using the GPU of the user's computer. In this way, the user will not have to download several gigabytes of data to view the videos, but only a few megabytes will be needed to take part in the exercises. Moreover, any modification to the pattern that should be used in the video can be done quickly and without having to re-encode the video, since it will suffice to modify the associated JavaScript code. The architecture of the web environment is shown in Figure 2.

The developed environment is described in Section V.

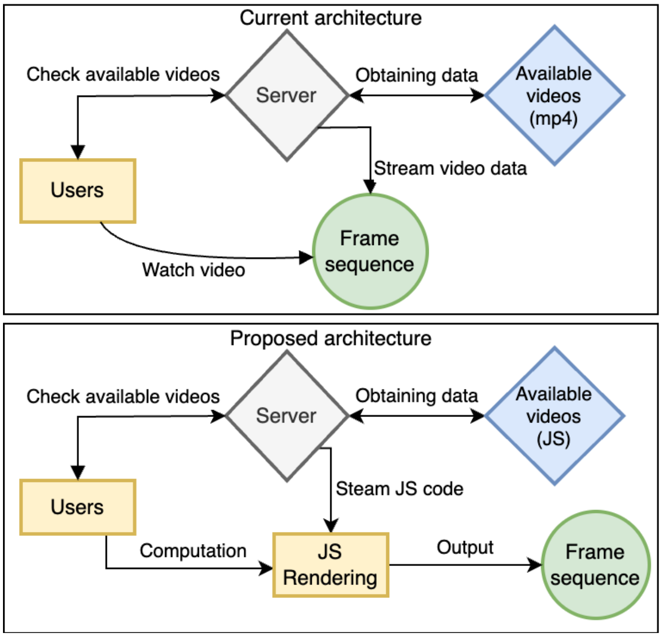

FIGURE 2. Architecture of the web application

IV. VIRTUAL REALITY APP

The application presented was developed using Unity, a platform designed for developing Virtual and Augmented Reality applications that allow exporting projects created for many platforms, including smartphone operating systems such as Android and iOS. Generally, Unity is used to make video games. Still, its versatility also allows the creation of applications of other nature, such as serious games [34], Digital twins, Interactive simulations, Virtual tours, and so on. During the development phase, it was necessary to define the minimum version of Android that would be supported. By analysing the current market share of Android APIs (Application Programming Interface), it was found that API 21, used by Android 5, allows the application to be available to 99.6% of the devices currently in use by users all over the world[4] and therefore it was selected as the version to be used. Instead, the target version was set to Google's latest release, which, at the time of writing, corresponds to API 33. Using the latest version of the target API is a requirement for publishing

[4]https://apilevels.com/

applications to the Play Store[5].

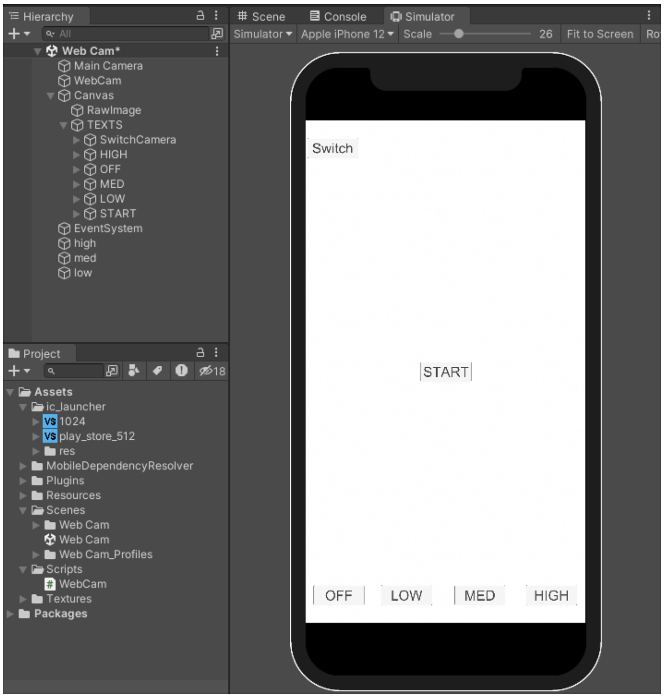

FIGURE 3. The mobile app development

The app's structure is shown in Figure 3. In order to simulate what people with VSS perceive, a 3D scene was created within Unity containing a *Main Camera* that has the task of capturing the content of the 3D scene and reproducing it on the screen. In addition, there is a script in C# that captures and saves the smartphone camera image in the application's working memory. In this way, it is possible to obtain a real-time video stream that scripts can manage. The main object that is present within the application is a Canvas. The image captured by the camera in real-time is displayed on it. Unity uses the Canvas as an object container (*Game Objects*). Inside the Canvas is a *Raw image* that is responsible for receiving and drawing an image on the screen. The image, before being drawn, is properly treated by applying graphic effects to it. In particular, a noise generator is used to simulate the effect of Visual Snow. The technical realisation of the noise effect is done using a *Post Process Volume*, a component that allows visual effects to be applied to a scene or a specific part of it after the background has been rendered. Generally, this is used to create particle effects such as fog, fire, or atmospheric dust and is intended to increase the immersiveness of the scene for a video game. This component can be used in an easily customisable and programmable way, according to the task's needs. We selected the Grain effect from the Post Processing Stack v2[6], which adds noise to the scene simulating the images of old cameras using chemical films. By configuring the settings in a customised way, it was possible to achieve an effect that was as close as possible to the one desired. Among the various parameters, we can define the colour of the grain we want to include in the scene; for this project, a black-and-white grain was chosen. The parameter *Intensity* then allows us to define the total number of particles shown on the screen and is very useful for simulating different intensity levels. The parameter *Size* defines the dimension of each individual particle shown on the screen. Four buttons have been added to the GUI to make the experience more customisable. The intensity parameter has been made dynamic, and its value can be varied at run time. Users can disable the effect and set it to a low, medium, or extremely intense level. Figure 4 shows the application running on an Android smartphone. One can see the user interface, the image captured by the camera and the Visual Snow effect in action.

If the phone is equipped with a front camera, a button in the upper left corner allows the user to switch the graphic input and use it instead of the rear camera.

The application's development also took into account Android Best Practices that require informing the user before accessing the camera or microphone. Considering the requirements in force as of August 2021, the compilation was done using the App Bundle format instead of the old *apk* format. Finally, regarding supported architectures, the compilation was carried out for both ARM64 (64-bit) and ARMv7 (32-bit) architectures. The size of the application installed on the device is 12 MB, which ensures minimal user memory usage. On the other hand, regarding system RAM consumption, a maximum usage of 32 MB was found to be a characteristic that makes the application work even on lower-end devices. The code of the Android application has been made open source and is available via GitHub[7].

V. THE WEB ENVIRONMENT

As the second part of the development project, a web platform was created in order to improve the user experience performing the exercises provided by the Visual Snow Initiative. The experimental program is called the "Visual Snow Initiatives Project" (VIP) and consists of a series of exercises lasting about 20 minutes to be performed daily. These exercises require the user to look at the computer screen while videos of static images are played, in which various shapes appear and move along the screen. These shapes can be squares or rectangles composed of video noise and move according to the pre-configured patterns on the user's display. Given the nature of these videos, which are characterised by a series of pixels that randomly change their colour, the size in megabytes becomes particularly large. This problem originates from the modern codecs used for video compression that work by optimising the matrix of screen pixels [35]. For example, if we try to compress a movie containing a soccer game, modern codecs would be able to reduce its size very effectively since most of the pixels would share a predominantly greenish colour, and

[5]https://developer.android.com/google/play/requirements/target-sdk
[6]https://docs.unity3d.com/Packages/com.unity.postprocessing@3.1/manual/Grain.html
[7]https://github.com/DamianoP/visualSnow2024

FIGURE 4. Android application running on a mobile smartphone where you can see the user interface and the Visual Snow effect recreated

this colour could likely even be shared between one frame and the next. However, these assumptions cannot be made in the case of footage containing video noise. A typical VIP project video requires a user to download about 1.8GB. If we want to view a live stream of one of these videos, users must have sufficient bandwidth to avoid problems, such as buffering.

Assuming a size of $1.8\,\text{GB}$, we get a megabit size of

$$1.8\,\text{GB} = 1.8 \times 1024\,\text{MB} = 1843.2\,\text{MB}$$

The videos have a duration of 20 minutes, which is equivalent to 1200 seconds. It follows that the required download speed in megabytes per second (MB/s) is given by:

$$\frac{1843.2\,\text{MB}}{1200\,\text{seconds}} = 1.536\,\text{MB/s}$$

Since $1\,\text{MB} = 8\,\text{Mb}$, the minimum download speed in megabits per second (Mbps) that is required is:

$$1.536\,\text{MB/s} \times 8 = 12.288\,\text{Mbps}$$

Therefore, to download a $1.8,$GB file in 20 minutes, a bandwidth of at least $12.288,$ Mbps is required. The proposed solution does not require constant data streaming but an initial download of a few megabytes.

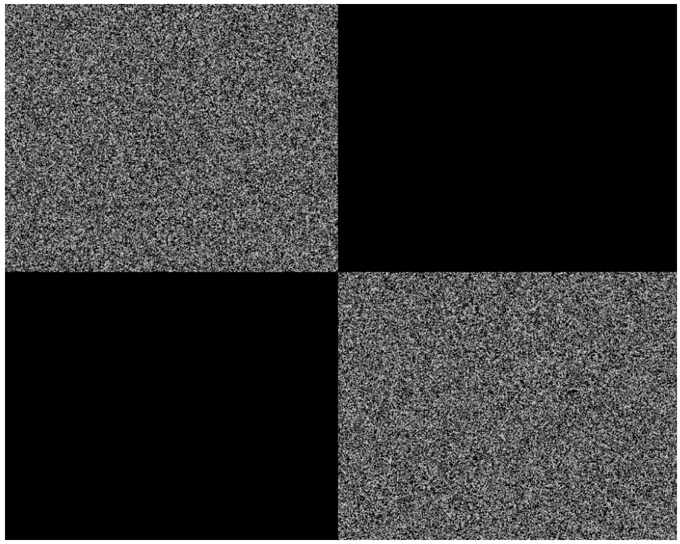

FIGURE 5. One of the exercises of the experimental programme running in the realised application is shown. Rendering takes place in real-time. The two figures containing noise move vertically filling the black background. Continuously their contents are filled with random noise.

The web platform is based on plain HTML and JavaScript and has been placed in a docker container to guarantee easy export and scalability. Docker makes it possible to increase the number of containers delivering the web page by allowing horizontal scalability [36] that can be configured by analysing the number of users simultaneously connected to the system and increasing or reducing the number of containers delivering the service accordingly [37]. The pages containing the actual exercises were created using Unity by exporting the various exercises via WebGL [38], a technology that allows applications to take advantage of the GPU and run within a web browser without the need to install additional components such as browser extensions or plugins. The main benefit of this technology is its portability, which allows users to enjoy content created in WebGL on various platforms. Running within the browser makes these applications independent of the operating system used by the user. This means that pages with exercises can be used through a computer or a Virtual Reality viewer such as the Meta Quest 3. Each scene in the Unity project represents an exercise and includes a UI canvas on which the graphical Shader is generated.

Using Unity to create new scenes or edit existing ones is much faster than re-encoding a complete 20-minute video because the whole operation can be done by scripting and programming the scene using Unity's animations. The language

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```
float4 frag(v2f v) : SV_Target{
  float2 uv = v.uv;
  uv.x *= _ScreenParams.x / _ScreenParams.y;
  float randomDisplacement = snoise(uv * float2
     (10.0, 10.0) + _Time.y) * 0.02;
  uv.y += randomDisplacement;
  float raindrop = snoise(uv * float2(600.0, 5.0)
     + _Time.y);
  raindrop = smoothstep(0.8, 1., raindrop);
  float3 rainColor = float3(1.0, 1., 1.);
  float3 finalColor = lerp(float3(.0, .0, .0),
     rainColor, raindrop);
  return _Color = float4(finalColor, 1.0);
}
```

Listing 1. HLSL code used to generate the noise effect used in one of the exercise

used to program the exercises is *HLSL* (High-Level Shader Language) [39], which is natively supported by Unity. An example of one of the exercises running on the web app is shown in Figure 5 and a portion of the code used to generate the noise effect is shown in Listing 1.

VI. DESCRIPTION OF QUESTIONNAIRE AND EXPERIENCES

This section describes the research that aims to validate the Android application and understand its merits and shortcomings. A questionnaire with multiple-choice questions was organised and provided to those who tested the software. Participation in the questionnaire was on a voluntary basis. In addition to the tests conducted in person, in order to gather as many opinions as possible, a post was published on the social network Reddit[8], which made it possible to disseminate information about the research conducted and enabled users from all over the world to participate in the evaluation phase.

A. DESCRIPTION OF THE QUESTIONS

The questionnaire consists of 10 questions, divided into three sections. The first section consists of general questions that aim to characterise the person responding to the test. The second section consists of questions about the users' evaluation of the smartphone application. Finally, the third section of the questionnaire is related to gathering users' opinions regarding possible future developments of this app and other software associated with visual impairments.

The first three questions ask about gender, age (to be indicated by selecting the user's age range), and whether a doctor diagnosed Visual Snow. The next question is about understanding how many years the user has been suffering from VSS. It is essential to establish the users' perception of this pathology since the scientific literature indicates that some people are born directly with it [7]. Finally, users are asked whether they also suffer from other visual pathologies that are often related to VSS, such as Eye Floaters, Blue Field Entoptic Phenomenon [40], Aura [41], Aura (only with migraine), Palinopsia, Sensitivity to light, Tinnitus, Depression or Anxiety.

The second part of the questionnaire is focused on the mobile application and is based on a Likert scale from 1 to 5, where 1 is a negative evaluation, and 5 is a positive one. Users are asked to rate the fidelity of the application's problem representation. People can compare the original image acquired with the smartphone's camera with the three proposed disturbance levels, selecting the one that best approximates the real-world effect. In particular, users are asked to evaluate whether this application helps them explain the problem to a doctor.

Historically, before the existence of this condition was acknowledged, people who described the problem associated with it were sometimes considered crazy or depressed by healthcare personnel [42]. Only recently, thanks to the technology advances, it has been possible to diagnose the problem [43]. Still, today, it is incredibly complex for people with VSS to explain the detailed characteristics of their poor vision to others, particularly to a doctor. This is why our work is vital to make such a complex visual effect clear and easily understandable.

The third part of the questionnaire carries out the app's final evaluation and collection of suggestions. The first question asks users to give a general and overall assessment of the application and their experience using it. This question is crucial because it allows us to understand whether the application is correctly designed for the users' needs. The next question asks users whether developing applications of this type is beneficial and whether they would like applications that can simulate other pathologies affecting vision. It is important to develop applications that can simulate diseases, and we want to validate this hypothesis with the users' answers. The final question of the questionnaire is open-ended. It allows people to express advice and opinions regarding the software so that, in the future, the app can even more accurately simulate the visual effect caused by VSS.

B. METHODOLOGY OF DATA COLLECTION

Participants in the questionnaire have received informed consent, which they must accept before proceeding with the questionnaire. Without the acceptance of informed consent, which explains how it is conducted and how and for how long the data are collected, it is impossible to access the questions and enter any answers. All data collected were stored in an anonymous database, so it is impossible to trace the participant's identity or associate the answers obtained with a specific person. The responses' timestamps were not stored, so it is impossible to trace the exact date on which a response was saved in the database.

VII. DISCUSSION OF RESULTS

This section reports the results of users' evaluation carried out both answering to a questionnaire provided using the open source LimeSurvey[9] platform (described in Section VI) and

[8] https://www.reddit.com/

[9] https://github.com/LimeSurvey/LimeSurvey

Please select you gender		
Female	Male	Not answered
27.67%	41.51%	30.82%

TABLE 1. Q.1, Gender specification

How old are you?						
10-17	18-29	30-39	40-49	50-59	60+	No answer
12.58%	50.31%	21.38%	7.55%	1.89%	1.89%	4.40%

TABLE 2. Q.2, Age specification

analysing the evaluations supplied to the app on the Google Play Store (described in Section VII-A).

It is worth mentioning that the questionnaire is anonymous and is conducted mainly using a web platform. The total number of people who participated in the data collection phase was 215; since not all questions are mandatory, the single questions had a variable response rate.

Question 1 asks the user to specify the gender. The results are shown in Table 1. A total of 159 people responded. The question shows that most of the participants are men.

Question 2 requires specifying the age of the participants. The results are shown in Table 2. A total of 159 people responded.

The data show that the majority of participants are young in the age group 18-29.

Question 3 requires specifying whether a doctor has diagnosed the existence of VSS. The results are shown in Table 3. A total of 159 people responded. The results show a meagre percentage of people with an official diagnosis (71.70%). This shows a lack of awareness of this disease and the need to detect its existence.

Question 4 requires specifying the number of years the participants have been living with VSS. The results are shown in Table 4. A total of 159 people responded. The answers to this question show that most of the participants have suffered from VSS all their lives. It is noted that 27.04% of the answers state that they have had it for about a year, which contrasts with some experimental observations that show that the type of disease has been present since birth [7]. In our opinion, it is possible that only after people became aware of the existence of this condition, they realise that they are affected by this syndrome.

Question 5 requires specifying whether other visual defects exist. The question is multiple-choice, so people can indicate several diseases, including Eye Floater, Blue Field Entoptic Phenomenon, Aura, Palinopsia, Sensitivity to light, Aura (only with migraine), Tinnitus, Depression, and Anxiety. All persons indicated at least one concurrent disorder at the VSS. The values found are very high, highlighting a probable correlation between these disorders. Analysing the answers, several pathologies appear to concur with VSS, the most frequent being Eye Floaters and Sensitivity to light.

Has a doctor diagnosed you as suffering from Visual Snow?		
Yes	No	No answer
21.38%	71.70%	6.92%

TABLE 3. Q.3, Diagnosis of existence of VSS

How many years have you been suffering from Visual Snow?					
All my life	20 years	10 years	4 years	1 year	No answer
32.08%	7.55%	11.32%	18.24%	27.04%	3.77%

TABLE 4. Q.4, Years of living with VSS

The results are shown in Table 5.

Question 6 concerns how the developed Android application can correctly represent the VSS. The question is based on a Likert scale, and the results are shown in Table 6. A total of 79 people responded. The 39.14% of the participants gave a score of 4 or greater.

Question 7 asks whether the application can be useful to make a doctor better understand their problem. The goal is to determine whether users of this smartphone app feel more confident in explaining their condition, even without knowing the precise terminology to describe what they experience daily. The values obtained are on a Likert scale. The results are shown in Table 7. A total of 79 people responded.

The 44.31% of the participants gave a score of 4 or greater. The analysis of the obtained results of Questions 6 and 7 shows that users feel more confident in explaining their condition when using an electronic device that represents their problem.

It is important to notice that some people who gave lower scores also added comments to the last question of the questionnaire afterwards. In the open-ended and free response, they explained that they would prefer to have a continuous variation of the effect (implemented as a slider) instead of fixed presets to more precisely vary the intensity of the effect and colour on the screen.

Question 8 is about the overall appreciation of the application whose rating is expressed on a Likert scale. The results are shown in Table 8. A total of 79 people responded. The 44.30% of the participants gave a score of 4 or greater. These responses mean that the application was highly appreciated by users who found it helpful for its purpose, which was to simulate the effect of VSS and easy to use.

Question 9 concerns the usefulness of developing similar apps for simulating other diseases, such as ocular Eye Floaters or the Blue Field Entoptic Phenomenon. Results show that 84.65% of people responded positively that it would be appropriate to focus research on the development of smartphone apps of this type as well. The results are shown in Table 9.

Question 10 is an open-ended question that allows users to express their opinions and suggestions for improving the application. The total number of people who expressed feedback by writing in the free text field is 35.44%. This percentage indicates that users' willingness to contribute to the project's development is significant, strengthening our will to continue

Do you suffer from any of the following diseases?								
Eye Floater	B.F.E.P.	Aura	Aura (with migraine)	Palinopsia	Sensitivity to light	Tinnitus	Depression	Anxiety
78.62%	69.81%	25.16%	16.98%	45.28%	71.07%	64.15%	44.65%	64.78%

TABLE 5. Q.5, VSS's concurrent disorders

Does the application represent your problem?					
1	2	3	4	5	No answer
3.80%	10.13%	30.38%	27.85%	11.39%	16.46%

TABLE 6. Q.6, Likert scale, App fidelity showing the VSS

Can the application help you explain your problem to a doctor?					
1	2	3	4	5	No answer
4.02%	3.80%	25.32%	25.32%	18.99%	20.25%

TABLE 7. Question #7, Likert scale, Help in explaining the problem to a doctor

developing this initiative. An example of feedback provided is the following: "*The static is different for any sufferer, it would be nice to set the density, colour, speed and size of the dots*", the comment is very constructive, and it is a suggestion that we will take into account for future developments. A user wrote "*If other symptoms like palinopsia, trailing, Blue Field Entoptic Effect could be visualized, that would be an extra plus*", this comment suggests that the user would like to have a more complete simulation of the symptoms that can be associated with VSS. Another comment we received was the following "*First of all thank you for this app <3 It will greatly help me to show my neurologist what I see precisely*", this comment was extremely encouraging for us and we are glad to have been able to help some users.

The comments obtained provide ample insights and room for improvement in the future. They point out that the app's use is of interest, and users would like more customisation to fine-tune the visual noise shown on the screen. The comments indicate that the app helps to externalise the characteristics of the symptomatology, aiding the doctor in understanding the patient's pathology.

Overall, how do you rate the application?					
1	2	3	4	5	No answer
5.06%	3.80%	27.85%	25.32%	18.99%	18.99%

TABLE 8. Q.8, Likert scale, Overall appreciation of the app

Do you think it would be useful to develop similar applications to simulate other visual pathologies such as Eye Floaters or Blue field entoptic phenomenon?		
Yes	No	No answer
78.48%	3.80%	17.21%

TABLE 9. Q.9, Development of similar apps for other diseases

A. USERS' EVALUATION MADE ON GOOGLE PLAY STORE

The application was also evaluated on the Google Play Store. The application was published on the Google Play Store on February 7, 2022 [10].

Analysing the statistics made available by the Google Play Console, an environment for developers to obtain useful data and analysis on their published applications, we can observe that currently, 78 users worldwide have the application installed on their smartphones. Figure 6 shows the trend of active users over time and the geographical distribution of the users. Figure 7 shows the total number of downloads over time.

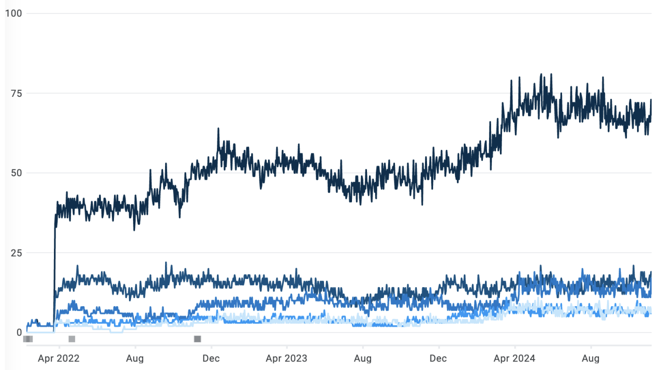

FIGURE 6. Installed audience (All users). All countries / regions (Black), United States (Dark Blue), Italy (Blue), United Kingdom (heavenly), Netherlands (Light Blue)

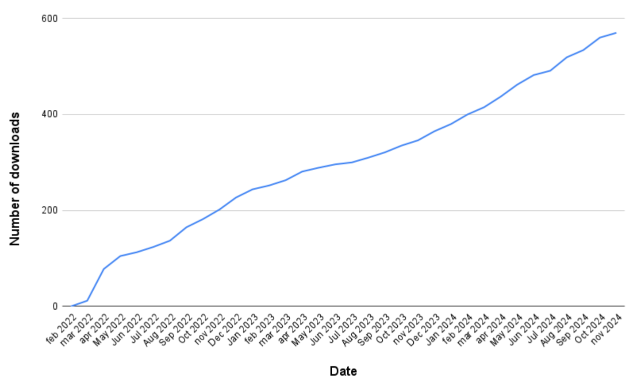

FIGURE 7. The chart shows the total number of downloads over time

The application has been downloaded about 580 times and received 4.8 stars out of 5. The application received 20

[10]https://play.google.com/store/apps/details?id=com.damianop.visualsnow

reviews with an average score of 4.95 out of 5. Analysing the reviews, we found that 1 gave 4-star review, and 19 gave 5-star reviews. Users who wrote reviews appreciated the application's ease of use and its usefulness in simulating the visual effect caused by VSS. The smartphones used have different operating systems, ranging from Android 10 to 14, which shows that the application is compatible with all the latest versions of the operating system.

The user who gave a 4-star review wrote *Would be 5 if you could mix colours, because I don't think any of us just sees dark noise, like me, that also sees white, yellow and red noise at the same time. Otherwise great app!*. One of the users who gave a 5-star review wrote *Very useful app. Simple and intuitive experience. I recommend to try it.* Other comments reiterated what was stated in the description of the comments to the questionnaire questions.

VIII. CONCLUSION AND FUTURE WORK

This work aims to help people with Visual Snow Syndrome by creating two software applications. The first is open-source software that can be installed on Android smartphones and made available for free in the Play Store. It simulates the visual perception of people with this condition. The second is software that aims to improve the accessibility of an experimental pathway made available by the Visual Snow Initiative. The pathway involves watching videos containing various patterns and effects of video noise. Since the compression of videos of this type is very complex, an application has been made that recreates these effects using the computational power of the user's machine. In this way, the user does not have to download several gigabytes of data to view the videos; only a few megabytes will be needed to participate in the exercises. Very positive feedback was obtained from the VSI association, which was very interested in the web-based exercise application. The Android software was evaluated through a questionnaire filled out by volunteer users. The results obtained for the first software are highly encouraging. Users have positively evaluated the Android application, and the number of people downloading it is increasing. As far as future developments of the Android application are concerned, user feedback and suggestions for improvement will be taken into account, such as implementing further functions via the user interface to vary the size and colour of the dots that make up video noise. The results obtained suggest that the development of applications that can simulate the perception of specific pathologies can greatly help people. The feedback collected and the data obtained from the questionnaire show that it is very important to develop applications that tell, describe, and simulate a pathology. These may be able to substantially help people who cannot express themselves correctly or who lack the correct language properties needed to make themselves understood correctly and fully explain what they are feeling, seeing, and perceiving. Future ideas for developing and continuing this research aim to improve the smartphone application that was presented and make the code compatible with Virtual Reality or Mixed Reality viewers. The same approach will also be implemented for the web platform for conducting exercises in such a way as to attest to its effectiveness in a condition of complete immersion of the user within a virtual environment.

ABBREVIATIONS

The following abbreviations are used in this manuscript:

API	Application Programming Interface
APK	Android Application Package file
AR	Augmented Reality
ARM	Advanced RISC Machines
BFEP	Blue Field Entoptic Phenomenon
GB	GigaByte
GPU	Graphic Processing Unit
HLSL	High-Level Shader Language
HTML	HyperText Markup Language
MB	MegaByte
MBCT	Mindfulness-Based Cognitive Therapy
RAM	Random Access Memory
UI	User Interface
VR	Virtual Reality
VSI	Visual Snow Initiative
VSS	Visual Snow Syndrome

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