Abstract—In the past decade, biometric authentication methods have received particular attention for their potential to enhance security and user convenience, surpassing traditional methods such as passwords, security tokens or other authentication modalities. Also, in response to constantly evolving threats, and the ongoing need to reinforce security measures, one promising avenue is the exploration of the pupillary reflex as a unique biometric indicator. The human pupil undergoes involuntary changes in response to external stimuli, and these reflexive alterations can be captured and analyzed for authentication purposes. The aim of this PhD thesis is to investigate how the pupil responds to specific visual cues, we hope to establish a reliable and non-intrusive means of authenticating individuals.

Index Terms—Security, Biometrics, Pupillary reflex, Authentication, Eye indicators

I. INTRODUCTION

As digital interactions have grown exponentially, so has the need for strong authentication methods, thus the evolution beyond traditional passwords to include smart cards and biometrics. While each of these techniques offer some security advantages, they also suffer from specific drawbacks. One of the main problems is their lack of resilience and usability issues. Passwords can be forgotten or compromised, smart cards can be lost or stolen, and biometric data, while nearly unique (depending on hardware accuracy), can still be spoofed or falsely recognized, meaning they can’t be renewed once compromised.

Considering all this, we may conclude that finding fresh leads is crucial. As the quest for an ultimate authentication method (if it exists) is ongoing, the purpose of our research is to break new ground in the direction of expanding biometric modalities, with a novel biometric technique that involves concentrating not on the inherent characteristics of the user, but rather on their responses to a specific stimulus. This technique has multiple advantages, especially being low-effort and easily renewable in case of data thefts. It employs pupil size as a measure to understand how visual stimuli activate reflexive memory mechanisms. Therefore, our intention is to explore the potential benefits of applying visual stimuli while dynamically measuring pupil biometrics.

II. RELATED WORK

A. Recognition memory for pictures

The 1960s have seen the birth of modern research into the human capacity to identify images. The earliest advances have shown that this ability surpasses the ability to recognize and differentiate previously encountered words, with high accuracy being achievable even months after the stimuli [1]. Regarding the structure and content of the picture representations in visual long term memories, another investigation has been suggested to provide insights. Others have also investigated how the structure and content of the picture affects memory, with performances for both significant and meaningless pictures evolving over the course of many weeks [2]. Additionally, this recognition process involves a degree of pre-conscious cognition, as demonstrated by the dilation of the pupil in response to visual stimuli which happens before it can fully percolate through the visual cortex, providing insight into the novelty of the stimulus [3]. That leads us to investigate the nature of that shift in pupil size, or what is known as the pupillary reflexes.

B. Research on the pupillary reflexes

Over the past 20 years, there has been an increase in interest in the use of pupillometry, or the measuring of pupil diameter. Thus the questions about the pupil size was raised since it could a simple, externally accessible physiological measure. First, it has been demonstrated by researchers that the pupil changes size in response to changes in ambient light (the pupillary light reflex). In addition, the pupil responds to a range of cognitive processes, including arousal, emotions and cognitive load. Studies into the relationship between pupil size and types of memory other than working memory (the limited quantity of knowledge that may be retained and applied when performing cognitive activities) are only in their early stages [4]. According to Võ et al., pupils dilate more when the subjects see words that they had seen in a previous study session [5]. Another research used vocal sounds, during both the exposure and test phases, pupils dilated more in response to vocal melodies than to piano melodies. Additionally, the response was higher for songs that had already been heard than for new songs. These findings offer the first proof that the identification of stimuli that unfold over many seconds may be measured using pupillometry [6].
III. PhD Focus: Application of Eye-tracking and VR-Technology

Pupil diameter dynamics serve as a valuable indicator for memory, especially concerning visual memory, given the profound influence of images on our recollection. Thankfully, the advent of modern eye-tracking technology, exemplified by VR headsets, enables us to extract precise data using integrated ocular metrics. Additionally, it allows us to exert greater control over the environment while automatically extracting key features. Leveraging these advancements, we aim to develop a reflexive memory authentication system which iteratively shows images to the user while measuring their response. Initially, the tests will focus on simple images, gradually incorporating more complex visual stimuli (including mosaics, visual secrets [7] or GAN-generated images) into our system. Our long-term goal is to obtain an infinitely-renewable authentication system that is low-effort but can generate at least 10 Sh/s of equivalent entropy.

IV. Materials and Experimental Design

Below are details on the specific components and the experimental design we plan to implement to ensure robust and insightful results.

A. Materials

The central component of this study is the virtual reality headset (HTC VIVE Pro Eye, HTC Corporation). The choice of this headset is explained firstly by the fact that we have more control over the environment (brightness, distance from the object, etc.), and secondly by its higher frequency compared to other off-the-shelf products: 120 HZ. The eye tracker is integrated into the virtual reality headset and records eye movements and measured data, then stored in the computer.

B. Experimental design

The experimental design involves a systematic approach to investigate pupillary responses to a visual stimulus within a virtual reality (VR) environment. After recruiting participants and obtaining informed consent, we will set up the HTC VIVE Pro Eye. The first dataset includes natural images whose content varies to evoke different pupillary responses. Prior to the experiment, individual calibration of the eye-tracking system will be conducted to account for variations in eye anatomy. Each trial will commence with a baseline measurement of pupil size in a neutral VR environment, followed by the presentation of images in a randomized order. The first phase will be devoted to image memorization (1 second per image), then a short interval to alleviate fatigue. Thereafter, a recall phase will occur while the size of the pupil will be continuously recorded. Post-experiment, additional data, such as subjective experiences through questionnaires, will be collected. The raw pupillometric data will undergo preprocessing, and statistical analyses to compare baseline measurements with those during image presentation. Overall, this design aims to contribute insights into the dynamics of pupillary responses to a visual stimulus using VR.

V. Conclusion

In conclusion, this experimental design offers a structured approach to exploring pupillary responses in virtual reality (VR) environments. We face many unknowns concerning the dependability and accuracy of biometric systems: in what time frame can the system distinguish between an unfamiliar and a known visual with accuracy? To what extent does the pupil’s response change when presented with images that are quite similar to ones they already know or have recently seen? Addressing these questions through interdisciplinary collaboration could enhance the reliability and applicability of findings, unlocking insights into human behavior and cognition in immersive VR settings.

REFERENCES