

ELE: CINEON'S EMPATHIC LEARNING ENGINE

USING EYE TRACKING IN VIRTUAL AND DIGITAL ENVIRONMENTS TO ESTIMATE AND ADAPT TO A USER'S STRESS, WORKLOAD, AND FATIGUE LEVELS.

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STRESS AND PERFORMANCE

Stress is experienced when the demands of a situation are perceived to outweigh the resources that a person has available to deal with that situation. It is usually considered a negative aspect of our lives, something that we should aim to reduce to increase our mental and physical well-being.

However, some stress can be beneficial and motivational, engaging us in difficult work and helping to sustain performance. For example, the pressure of a forthcoming competition can help an athlete to maintain focus and train harder. However, if stress is extreme or persists for too long, it can lead to the negative emotion of anxiety, which counter-productively disrupts performance.

Anxiety is, by definition, an unpleasant experience. It involves feelings of worry and apprehension, causing thoughts to race, and may create strong physiological responses like sweaty palms, increased breathing, and a raised heart rate. These effects can distract and derail attention from the task at hand, leading a person to focus unnecessarily on themselves, or on other unhelpful negative stimuli.

People tend to feel best about their performance with just the right level of stress. Too little and they may find something too easy or boring and consequently may not perform at their optimum. Too much and they might be overwhelmed, find it difficult to focus, and perform poorly.

Ensuring that stress is neither too low nor too high can support the health, performance, and efficiency of humans across a wide variety of interactions and tasks.

There is a 'Goldilocks' zone in the relationship between stress and performance. This will vary in the context of the task at hand but can generally be visualised via the Yerkes-Dodson Law - an inverted 'U' shape as shown in Figure 1.

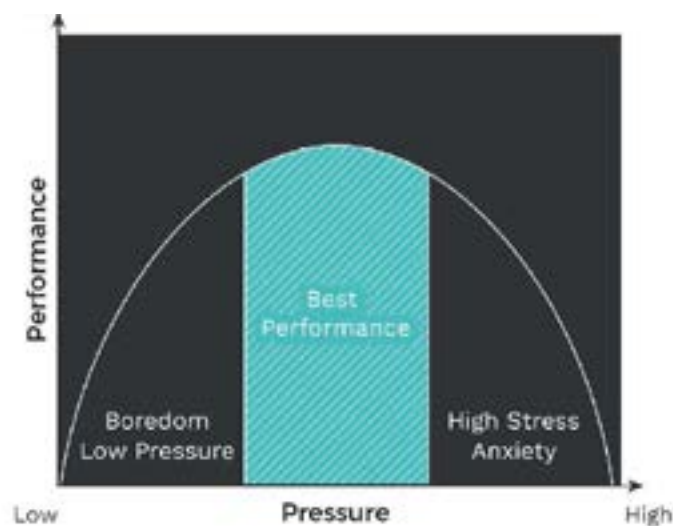


Figure 1.

WORKLOAD AND FATIGUE

Workload refers to the amount of cognitive processing a person is doing. A high workload might be caused by a single task that is highly complex, or by a multitude of more straightforward tasks where the difficulty arises from needing to perform them at the same time.

Similarly to stress, we can think of people performing well when their workload is well balanced. Too much workload and a person might start making mistakes and become fatigued; too little and they may become bored. Individuals tend to perform best when they have a reasonable workload placed upon them, such that they have some, but not too much, spare capacity.

However, while workload and stress are often correlated, they are different features of cognition. Someone may be stressed despite a low workload, and a high workload may not be stressful to some individuals. Stress also depends on the nature of the workload, with some sets of difficult tasks causing stress while others do not. Depending on individual competency and training, the same task may not constitute a high workload for different individuals. Even if a task does generate a high workload, this workload may or may not cause stress in different individuals, depending on their capacity for the work.

Fatigue may result from high stress or workload but may also be caused by external factors such as poor sleep. Fatigue is characterized by a significant reduction in mental efficiency, motivation, and sustained attention, making it difficult to complete tasks that are normally easy. While some fatigue is inevitable, high fatigue leads to poor human performance with reduced efficiency and motivation.

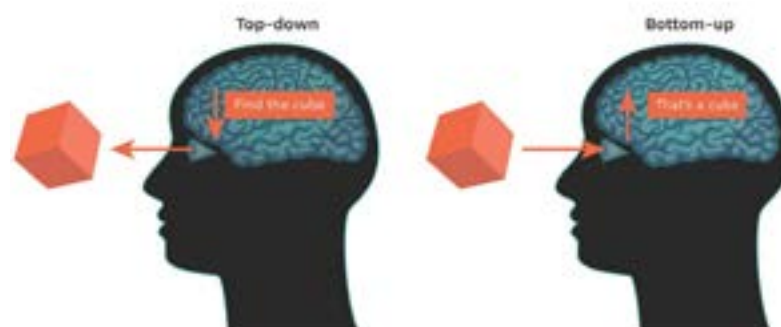
ESTIMATING COGNITIVE STATE WITH EYE-TRACKING

We can infer someone's stress, workload, and fatigue levels, without asking them directly, leveraging technology that can track a user's visual attention. This is because cognitive state affects how the eyes behave. Eye-tracking allows us to monitor where someone is looking, the gaze pattern and strategy they have adopted, how their pupil-diameter is changing, and whether their eyes are open or closed. Someone who is too stressed becomes easily distracted and might focus on the wrong things. Someone who is under a high workload may fixate for longer durations as they attempt to absorb information. Someone who is fatigued may blink more often and may switch focus more slowly.

Decades of research have shown that over stressed, overloaded, and over fatigued individuals experience distinct changes in how they control their visual attention. These changes are revealed in the ways their eyes move. Therefore, the eyes provide a portal into their underlying cognitive state.

The way that stress reveals itself in a person’s eye movements is reasonably consistent, with stress usually associated with an inability to inhibit distraction, and less efficient collection of task-relevant information. For example, high stress during a complex aiming task like a golf putt might lead to fewer gaze fixations on important visual areas, but more overall fixations as the eyes move about the scene. In contrast, cognitive overload when a pilot is learning to fly a plane can lead to erratic and unpredictable eye movements. These patterns can be quantified and related to workload in real-time, enabling live visualisation and assessment of stress, workload, and fatigue levels through eye movements alone.

The effects of cognitive state on visual attention have been well-studied by psychological scientists and mental-health researchers. Where we direct our visual attention is guided by both our current goals and motivations (top-down) and visual characteristics of the environment (bottom-up). Different brain networks underlay these attentional systems. These networks work cooperatively under normal conditions. However, either fatigue or highly demanding or stressful situations can affect attentional control, reducing the effectiveness of top-down (goals and motivations) processing. This leads to an over-reliance on bottom-up (stimulus driven) visual attention. This switch in attentional control affects how the eyes behave. Studies based on experiments that require some inhibition (or target-locking) of gaze have consistently provided evidence for reduced top-down control of eye movements under stress, workload, and fatigue.



 THE SCIENCE: ELE AND MACHINE LEARNING

To provide accurate estimates of stress, workload, and fatigue across a range of contexts, our data-science team create and validate AI machine-learning models using data collected by our research team. We call the suite of models, the API used to access them, and the dashboard used to view them, ELE: the Empathic Learning Engine.

To ensure that our models can generalise across individuals, over time, between tasks, and under different attentional demands, we collect rich data from volunteers across a range of virtual and real-world experiences. We ask participants to provide frequent feedback on their emotional state, allowing us to relate eye-tracking patterns to cognitive state. This forms the basis of our continuously improving AI models.

Our approach for establishing ground truth is simple and evidence based: Subjective perception measured through self-report is the basis of our ground truth. We believe that the subjective experience of the individual is key. How stress, workload, or fatigue are subjectively experienced affects performance more than any independent physiological measure. A strong method for self-reporting is therefore crucial; our approach is frequent and non-invasive questioning, allowing us to capture the variation of the subjective psychological state over time.

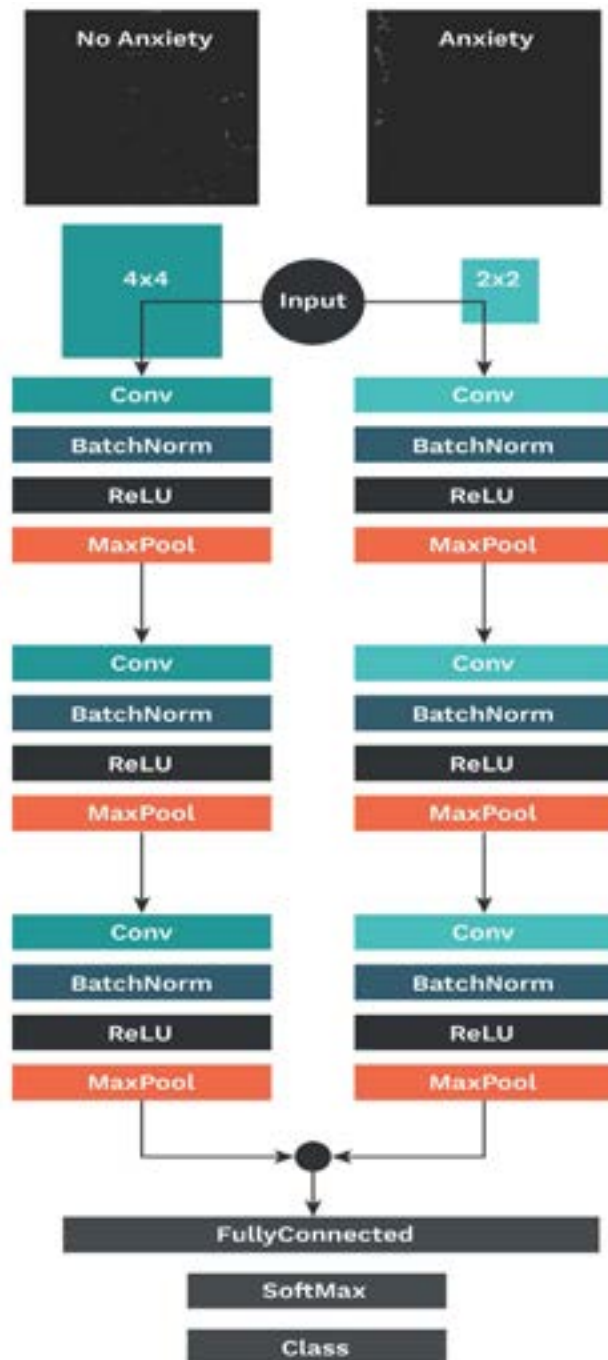
In contrast, other signals such as heart rate that are sometimes correlated with stress and workload are usually validated in their correlation using self-reported scales, introducing some circularity.

Pupillary response and activity have been correlated with cognitive workload. Blink frequency, duration and patterns have been correlated with fatigue. We use these metrics to validate the datasets, but to avoid circularity, they do not provide a ground truth.

Introducing variation in the training data is key. We create a range of subjective experiences through experimental manipulation. This variation is crucial to training models that can generalise across tasks and between individuals. For example, participants are asked to give a short talk after a task, which usually increases the perceived stress level. Variation of each construct is counterbalanced within tasks and activities to avoid models learning visual context only.

Once the data are collected, a variety of machine-learning methods can be applied: Performant deep-learning approaches can ingest almost-raw eye-tracking data and uncover subtle features in the data that are impossible for

humans to detect and that relate to cognition. Feature-based models use bespoke characteristics that are extracted from the data and that are known to correlate with cognitive state. Since machine-learning can be difficult to interpret alone, we also craft heuristic models based on trends between eye behaviour and cognition that have been identified in the literature.



The outputs of these models are made accessible through the ELE Dashboard, a visual analytics interface designed to transform complex behavioural and physiological data into clear, interpretable insights. The dashboard enables rapid exploration of stress, workload, and fatigue dynamics across time, tasks, and individuals, without requiring specialist data-science expertise. By linking model outputs to task events and performance measures, the dashboard supports both retrospective analysis and applied decision-making, enabling users to better understand how observed cognitive states relate to attention, perception, and performance in real-world scenarios.



 GAZE-STRATEGY IDENTIFICATION

We can also use machine learning and other pattern-recognition techniques to detect specific strategies of eye movement from timeseries of gaze data. This information can be used to determine if specific manoeuvres are being performed properly. For example, when driving a car and turning there are specific patterns of eye movement that correspond to a good performance (e.g., checking the road is clear, checking mirrors) and these can be identified in data. When flying a plane there are certain instruments that must be consulted in a specific order before carrying out a manoeuvre.

In gaze-strategy mode, ELE can look for patterns either learned from training data or characterised in advance by experts. ELE uses a combination of machine-learning and fuzzy matching to identify and score potential instances of a strategy occurring in data and this can be provided as feedback to instructors.

Examples of gaze strategy detection range from the identification of relatively simple features such as fixations (eyes focussing on one specific target) and saccades (eyes moving between targets) to specific constructs such as effort (defined as the number of saccades over a specific period) and focus (sustained fixation of both eyes and head associated with a specific target).

Further to these, ELE can automatically identify on the timeline instances of task-based gaze strategies. Some of these are well understood in the relevant literature, while others derive from cognitive task analysis undertaken by Cineon across a range of contexts. Examples here include radial and arching scans on flight decks, which are associated with good situational awareness as well as trained strategies such as LOIs (Limitation, Operation, Indication). Other gaze strategies include directional sweeps of an area for targets during military room-clearance operations, or differing eye-movements associated with ventral and dorsal attention modes associated with effective performance in industrial workers.

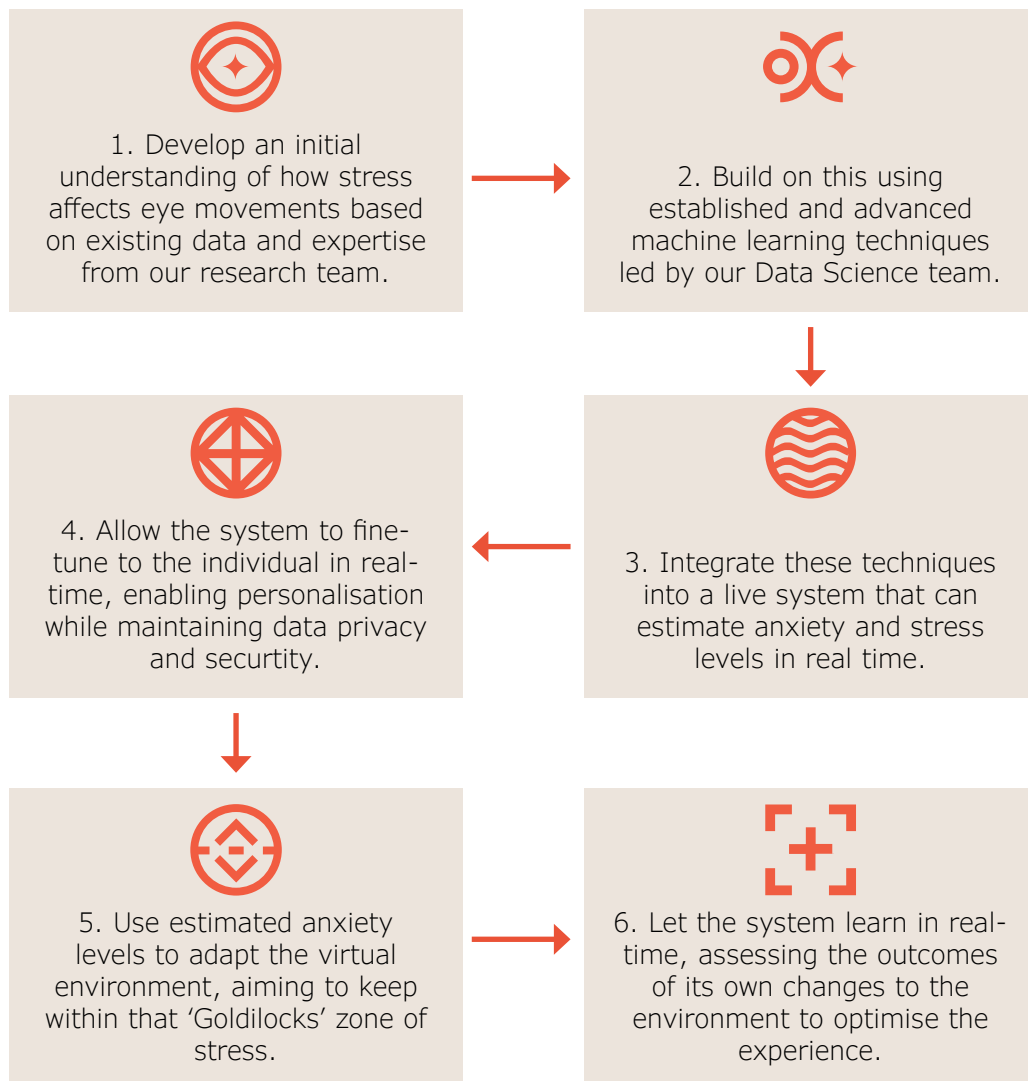
We refer to gaze strategies that are associated with task success or good performance as Eye Indicators of Competency (EIOCs).

ADAPTIVE VIRTUAL ENVIRONMENTS ARE MORE INTELLIGENT

Cineon are combining the estimation of stress, workload, and fatigue with an adaptation engine, which will enable a virtual or digital system to not only intuit the emotional state of the user, but to make changes to the environment to suit their state of mind.

By leveraging the integration of eye-tracking with virtual reality hardware, we can therefore create emotionally intelligent software that detects and adapts to a user's stress level.

OUR PROCESS:



We are currently focusing our efforts on stress, workload, and fatigue via eye-tracking because we have compelling real-world use cases. However, the possible use cases of ELE are wide-ranging.

A decorative icon consisting of a cluster of small red dots arranged in a roughly square shape.

SECURE AND ETHICAL TOOLS

A key consideration when collecting and processing eye-tracking data is the consent and privacy of the user.

At Cineon, we are dedicated to upholding the privacy and security of all individuals whose data we handle. Our company vision is to develop secure and ethical digital tools that improve health, performance, and productivity. In practice, this means we operate under four pillars of data security when using eye-tracking and other physiological data:

1. KEEP DATA ANONYMOUS

As soon as possible after we collect data it is completely anonymised. We sever any connection to personally identifiable information.

2. KEEP DATA MINIMAL

We don't collect unnecessary data that we don't need for our products. For example, we would not collect iris data, despite the availability of this from some eye-trackers, because this is not thought to be helpful for our ability to estimate emotional state.

3. KEEP DATA SECURE

All records, even when anonymised, are kept on secure servers with managed access. However, even if this were breached, the data that we do save could not be used to identify individuals.

4. KEEP OUR DATA PROCESSES OPEN

All our data processing is provided with informed consent from users, and our data-management procedures are clearly explained in our Privacy and Security Charter.



→ CASE STUDIES

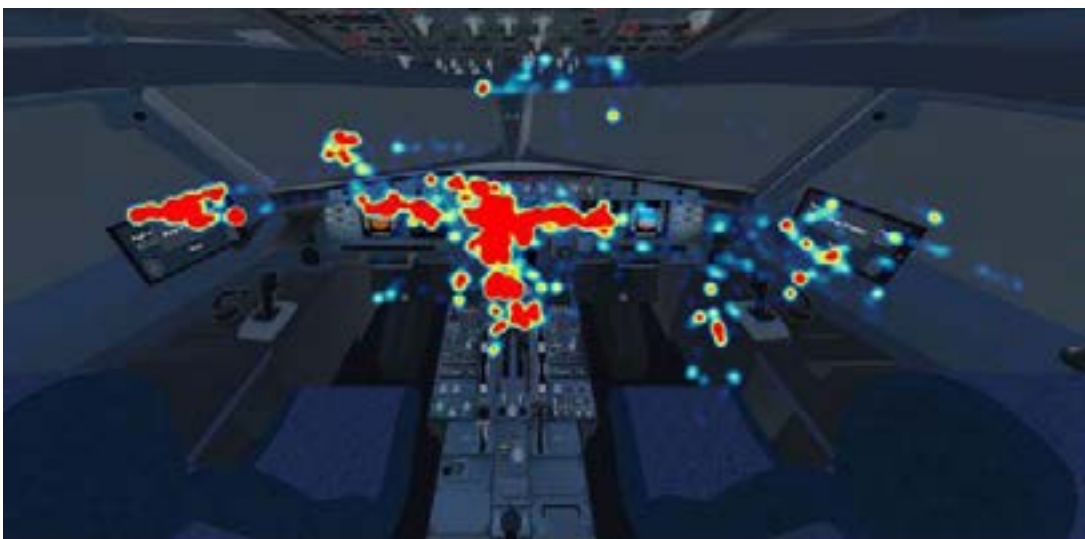


AVIATION

TRAINING AIRCREW COMPETENCY USING EYE-TRACKING (TACET)

The root causes of most aircrew accidents are related to non-technical competencies, such as workload management, decision-making, and situational awareness. These competencies are difficult to assess through observation by an instructor. TACET systematically captures critical performance and psychological insights based on eye tracking. This objective analysis serves as a measure to help instructors evaluate various pilot competencies and levels of expertise through auto-detection and timeline analysis of specific gaze features.

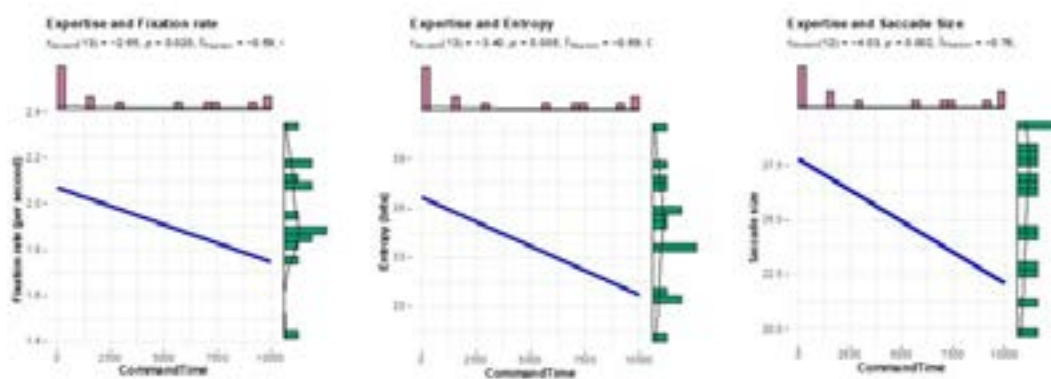
Cineon and the University of Exeter undertook research into the fidelity and validity of the software using a cohort of airline pilots with differing levels of experience. The results were published in the International Journal of Aviation Psychology (see references).



Differences were found between more experienced pilots on some Eye indicators Of Competency (EIOCs):

Entropy describes the level of randomness or variability in eye movements. Measuring entropy can therefore assess whether a pilot is performing a structured and systematic scanning pattern, or a highly variable inefficient one. High entropy indicates more random eye-movements. It was found that more experienced pilots showed less random eye movements.

EIOCs (entropy, fixation rate and saccade size) were all sensitive to the number of aircraft command hours, which translated to shorter saccades, a lower fixation rate, and less random fixations.



Expertise was strongly related to a particular pattern of searching featuring more saccades from west to east, and fewer saccades from south to north. This suggested that more experienced pilots had a particular scan pattern that underpinned their performance.



As well as identifying specific correlations between eye-movements and experience, TACET was also deployed to identify specific 'taught' gaze strategies which include LOI's (Limitation, Operation, Indication), radial scans and convex-hulls scans. These were detected by the software even in instances where they had not been identified by instructors.



TACET WALKAROUND

TACET Walkaround, a dedicated module within our flagship TACET platform, was created to modernise one of aviation's most safety critical tasks: the pre flight inspection. Developed in partnership with Jet2.com, the solution provides a high fidelity, repeatable virtual environment where pilots can practise realistic walkaround procedures without being limited by aircraft availability, weather or operational restrictions.

TACET Walkaround uses in-VR eye-tracking to provide an objective measure of inspection success (i.e. whether key inspection points have been viewed) and also whether the fixation duration was sufficient to ensure that the view was part of a systematic inspection routine. The system is ELE integrated to provide a measures of gaze efficiency and distraction which are known markers of inspection competency.

Jet2 were instrumental in shaping the training experience and have now deployed the system across their Manchester and Bradford training centres, marking a significant step in adopting immersive and measurable pilot training technology.

TACET Walkaround has become the first VR based training device to gain approval from the UK Civil Aviation Authority (CAA) as an Other Training Device for pilot training, allowing airlines to use it as an alternative means of compliance.

TACET Walkaround uses eye tracking and behavioural data to objectively assess scanning efficiency, situational awareness and hazard detection, strengthening Competency Based Training and Assessment across fleets.



DEFENCE AND SECURITY

ADAPTIVE ROOM CLEARANCE TRAINING (RCAT)

This project was undertaken on behalf of the Defence Science and Technology Laboratory (Dstl) in collaboration with the University of Exeter.

Effective room clearance drills are characterised by the ability of a team of operators to rapidly enter a space and eliminate targets while minimising the risk to operators and non-combatants.

Cineon created unique eye-tracking-based VR software as part of a series of military studies. These included the testing of adaptive virtual training designed to coach improved performance through the use of real-time scenario adaptation / personalisation.

The overall aim of these projects was to explore the efficacy of concepts and techniques from the field of skill acquisition and training: virtual reality (VR) technology; eye movement training; and eye tracking technology and analysis. Methods of 'augmenting' VR training were developed to maximise the effectiveness/efficiency of this type of training.

VR offers opportunities to augment or improve training in ways that may not be possible in the real-world, such as through automated personalised feedback or real-time learning cues. An innovation of the project was the implementation of eye-movement training methods within VR. Eye movement training aims to accelerate the learning of visually guided skills, such as aiming a weapon, by teaching the eye movement patterns of experts to novices. Feed-Forward Eye Movement Training (FFEMT) presents trainees with a point-of-view eye movement recording of experts as a model to follow, while Feed-Back Eye Movement Training (FBEMT) shows trainees recording of their own eye movements to learn from. Previous research has demonstrated these methods to be effective for accelerating learning of both sport and surgical skills.

The results showed an overall improvement in performance in the VR environment, but no group or interaction effects, which suggests that participants generally improved regardless of their specific training. Analyses of eye movements showed that many of the variables changed from pre-post training in line with performance, thus confirming their important role in the task. Fixation duration and search rate changed most from pre- to post-training in the FBEMT group, suggesting more efficient scan patterns and indicating an effect of the FBEMT on some of the visual processes related to room clearance skill. Furthermore, there were also the largest improvements in the anti-persistent saccade measurement for the FFEMT group. Analyses of self-reported workload and presence suggested that the VR task was immersive and not overly demanding.





HEALTHCARE

IMPROVING SERVICE ACCESSIBILITY WITH VIRTUAL EXPOSURE (ISAVE)

Missed MRI scans due to patient anxiety lead to poor patient outcomes and are costly for health-service providers. This issue costs the NHS alone £11M annually in terms of missed appointments. Research suggests this is partly due to fear and anxiety around the scanning experience.

Cineon worked with the NHS to develop a virtual MRI scanning simulator that can automatically adapt to a user's anxiety levels and fear-response. This provides a non-threatening means of helping users prepare for their scanning appointments.

Using eye-tracking, we can estimate anxiety levels to inform automatic adaptations of the virtual experience, such as assistant support, noise, time spent in the scanner, and calming interventions. Combining these passive measurements with explicit self-reports (i.e. asking participants directly how anxious they are feeling), can provide an optimised, personalised exposure-therapy treatment.

iSAVE was subject to 'Service Evaluation' within the NHS and experimentally by an academic research team at the University of Exeter. The research team concluded that the potential for the use of VR lies in its ability to closely replicate the real world as a preparatory and exposure technique for those likely to experience concerns over the MRI procedure itself. Testing of a prototype indicated that 80% of patients who had previously failed to attend an appointment were able to undertake a scan after using it.

With funding from Innovate UK, Cineon enhanced iSAVE by developing the anxiety model further, creating mechanics for real-time adaptations, and making the software user-friendly and narrative driven. iSAVE now offers a personalised and more immersive experience, ensuring patients receive the most effective preparation for their assessment or treatment. The software has since been applied to other use-cases including in a support tool for those experiencing occupational stress.



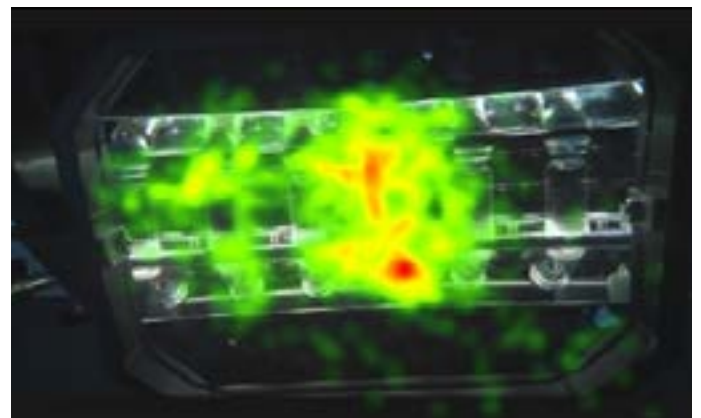
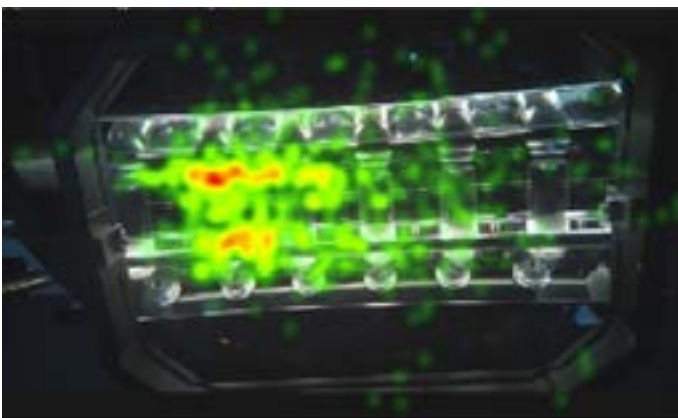
PHARMACEUTICAL

⚠️ PRODUCTION LINE INSPECTION WITH EYE-TRACKING

Cineon investigated the factors relating to competency in 'injectables' production line quality control operatives. The role requires operators to view vials moving along a conveyor using apparatus that combines magnifying lenses and mirrors to enable them to view all parts of the vial during the continual process.

Operators were asked to perform inspection tasks while wearing eye tracking glasses, and the subsequent eye tracking analysis provided an insight into the perceptual skills required to perform this task effectively.

The figures below show heat maps of fixation locations during a real-world inspection task in a more experienced operator (left) and less experienced operator (right).



Performance related differences between subjects were related to the specific perceptual strategy they used. As is illustrated above, subjects appear to have two distinct techniques for perceiving and identifying defects; on the left-hand image, subjects scan the tops and the bottoms of the vials, and do so early in the process, only scanning briefly later to confirm; on the right-hand image, subjects display a more scattered visual search pattern, and do so much later in the process, affording them less time for secondary checks. This is in line with previous literature relating to medical image scanning and interpretation (Wood et al., 2013; Brams et al., 2019).

These findings enabled the development of a VR simulation of the task that used the principle of Feed Forward Eye-Movement Training (FFEMT) to coach operators to adopt an effective gaze strategy more rapidly. The simulation also enabled operators to improve their perceptual skills in a risk-free environment without the need for complex and costly machinery, and without to production.



INDUSTRIAL



EYE-TRACKING FOR THE DEVELOPMENT OF REFINERY SAFETY TOOLS

While the refinery industry has reported a reduction in incident rates, with zero fatalities as its goal, the sector is not yet where it needs to be. Simulation training is used extensively in many high-risk and safety-critical industries, including military, aviation, medicine and sport.

There is a growing and compelling evidence base to suggest that simulation is an effective and efficient way to train humans to perform safely under pressure. Concawe (a leading association of the European petroleum refining industry) engaged Cineon and the University of Exeter to explore this potential. The consortium developed and tested a state-of-the-art virtual reality simulation training tool, which allows trainee operators to experience an operator tour of a refinery unit and to practice observational, manual and complex decision-making skills. Within the virtual environment and in supplementary training material, trainees learnt about the underlying human process relating to human perception (eye movements), based on eye tracking research undertaken by Cineon at the Total refinery in Antwerp.

Cineon collected eye-movement data from refinery workers and undertook cognitive task analysis of the videos. We were able to identify evidence of both 'goal-directed' and 'stimulus driven' attention modes in operators associated with different types of refinery tasks. There was also evidence of the deployment of systematic and logical scanning patterns in experienced operators. These findings enabled the development of a simulation with similar task types and stimuli densities to the real world.

The training tool was first tested with a small sample of refinery operators. The study provided some initial proof-of-concept, with evidence to support both the face validity (the extent to which operators agree that the simulation is realistic and convincing), and construct validity of the simulation. This

face validity was corroborated by attendees of the Concawe Symposium in Antwerp in March 2019, in which 50 people experienced the simulation. While face validity is important, perhaps more important was the evidence for construct validity. Here, through an assessment of the perceptual capabilities of operators in VR (how quickly and efficiently they detected hazards) we were able to show that their experience and skill advantage in the real-world translated into the virtual world. More specifically, the virtual tool, and the metrics it provides, were able to discriminate the skill level of the user. This is an important validation step that is performed on simulations in many industries including aviation and medicine.



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