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Modélisation du regard d'experts pilotes comme guide attentionnel pour l'entraînement de novices.

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Résumé

Les compétences de surveillance du poste de pilotage des pilotes professionnels, communément appelé *monitoring* en anglais, ont été rapportées à maintes reprises comme un facteur commun causant des accidents de transports aériens. Conséquemment, l'industrie aéronautique et la communauté scientifique évaluent divers moyens d'entraîner les compétences visuelles des pilotes d'avion. La littérature concernant l'évaluation et l'entraînement de stratégies visuelles fournit plusieurs pistes, notamment l'utilisation de l'oculométrie. Pourtant, peu de recherches ont évalué le potentiel d'entraînement de stratégies visuelles chez les pilotes novices. En utilisant cette technologie, ce mémoire évalue la valeur d'utiliser la représentation du regard d'un expert comme guide attentionnel dans le cadre d'une vidéo de formation aux stratégies visuelles pour pilotes novices. Pour ce faire, les cadres conceptuels que sont la théorie cognitive de l'apprentissage multimédia et la théorie sociale de l'apprentissage servent de fondements théoriques. Lors d'une expérience inter-participants, vingt-trois pilotes novices ont participé à une expérience les exposant à une de deux versions de vidéo formation aux stratégies visuelles entre deux tâches de vol en simulateur. Les mesures de comportement oculaire et un questionnaire sur la valeur perçue du vidéo par les participants ont permis de démontrer un bénéfice significatif au processus d'apprentissage de stratégies visuelles chez les pilotes novices. Nos résultats suggèrent que les participants exposés au regard d'expert ont manifesté un comportement imitant celui des experts. L'analyse des performances manuelles ne permet toutefois pas de détecter une amélioration à la suite de l'exposition à cette vidéo. Cette expérience fait l'objet d'un article scientifique qui présente une revue de la littérature, les hypothèses, la méthodologie de l'expérience et les résultats. Plusieurs pistes de recherches futures sont également proposées en conclusion de cet article et de ce mémoire. Le mémoire se termine par une synthèse de l'étude adressée à un public professionnel et interprète les résultats afin d'augmenter la portée de diffusion de cet article scientifique.

Mots clés: Oculométrie, simulateur de vol, stratégies visuelles, entraînement de pilotes, compétence de vol manuel, TCAM, conscience situationnelle, expérience utilisateur, attention visuelle, regard d'expert

Abstract

The monitoring skills of professional pilots have been reported as a common factor in air transport accidents on multiple accounts. Consequently, the aviation industry and the scientific community are evaluating various ways of training the visual skills of aircraft pilots. The literature on the assessment and training of visual strategies provides a number of avenues, namely with the use of eye-tracking technology. However, little research investigated the potential value of training visual strategies in novice pilots. Drawing on the conceptual frameworks of cognitive theory of multimedia learning and social learning theory, this thesis evaluates the value of using the representation of an expert's gaze as an attentional guide in a visual strategy training video for novice pilots. In a between participant experiment, twenty-three novice pilots participated to an experiment exposing them to one of two versions of video training in visual strategies between two simulator flight tasks. Measurements of ocular behaviour and a questionnaire on the value of the video perceived by the participants demonstrated a significant benefit to the process of learning visual strategies in novice pilots. Participants exposed to expert gaze showed behaviour mimicking that of experts. Analysis of operating (i.e., manual flight) performance did not reveal any improvement following exposure to the video. This experiment is the subject of the first article presented, which includes among other things a literature review, the experimental methodology and the results. Several avenues for future research are also proposed in the conclusion of this article and thesis. The thesis ends with a synthesis of the study aimed at a business audience and interprets the results to increase the reach of this scientific paper.

Keywords: Eye-tracking, flight simulator, visual strategies, pilot training, manual flight skill, CTML, situation awareness, user experience, visual attention, expert gaze

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Liste des abréviations

AOI	Area of interest
CTML	Cognitive theory of multimedia learning
EMME	Eye movement modeling example
GETAMEL	General extended technology acceptance model for e-learning
GTE	Gaze transition entropy
IATA	International air transport association
NDB	Non-directional beacon
PEOU	Perceived ease of use
SA	Situation awareness
TAM	Technology acceptance model
TC	Transport Canada
UI	User interface
VOR	VHF omnidirectional range

CQFA	Centre québécois de formation aéronautique
TCAM	Théorie cognitive de l’apprentissage multimédia

Avant-propos

Le présent mémoire a été rédigé en suivant une structure par article conformément aux exigences du programme de Maîtrise ès Science en Gestion de HEC Montréal.

Le premier article évalue l'impact de l'utilisation du regard d'un expert comme guide attentionnel dans un vidéo d'entraînement des stratégies visuelles de pilotes novices. Cet article est en préparation en vue d'une publication éventuelle. L'article est présenté avec l'accord des coauteurs.

Le second article est de nature managériale et est constitué d'une synthèse et interprétation des résultats. Le niveau de vulgarisation de l'article vise un public plus large en vue d'augmenter la portée des résultats de cet article et le rendre accessible à une plus grande communauté d'acteurs d'affaires.

Remerciements

J’aimerais remercier plusieurs personnes qui ont contribué de près ou de loin à mon parcours aux cycles supérieurs, sans qui ce parcours ne se serait pas avéré aussi enrichissant.

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Chapitre 1
Introduction

Le présent mémoire s'inscrit de façon générale dans les sciences cognitives et l'expérience utilisateur, plus précisément dans l'ensemble des recherches analysant le regard humain pour comprendre les processus cognitifs sous-jacents. Ces processus cognitifs sous-jacents seront étudiés pour fournir des pistes de solution afin de façonner les nouvelles technologies de façon à ce qu'elles s'adaptent à nous. L'objet du présent mémoire est donc de fournir une synthèse de l'évaluation d'une technologie spécifique, *le guidage du regard via la représentation du regard d'un expert,* pour un contexte particulier, *la formation de pilotes novices*. L'industrie aéronautique a toujours été un terreau fertile pour la recherche, contexte propice à l'exploration des limites de la science.

Pour que le transport aérien demeure une des méthodes de transport les plus sécuritaires, des organismes mettent en place des normes encadrant les bonnes pratiques pour enquêter sur les accidents de transport aérien. Les entités gouvernementales responsables des enquêtes suivent ensuite les normes et recommandations appropriées. Ces enquêtes ont permis au fil du temps d'identifier les causes d'accidents les plus importantes. Lorsqu'il y a identification d'une cause d'accident, l'industrie et le milieu scientifique réagissent en conséquence et tentent d'apporter des explications et des solutions pour comprendre et régler la situation. Un rapport produit par une entité gouvernementale (I.A.T.A, 2016; United States. National Transportation Safety, 1994) expose que plusieurs accidents depuis les années 1990 ont été causés ou aggravés par une lacune dans les compétences de monitoring du poste de pilotage chez les pilotes. On trouve en effet que certains pilotes bénéficiant d'une expérience considérable ont des comportements oculaires en vol qui pourraient contribuent au risque d'accident (Abbott et al., 2013; I.A.T.A, 2016). Des rapports de plusieurs organismes ont depuis demandé que la formation sur l'adoption de comportements oculaires efficaces pour le monitoring soit intégrée aux formations de pilotes professionnels.

L'apprentissage a toujours été de grand intérêt pour l'industrie aéronautique puisqu'elle a un impact direct sur la sécurité et se développe en un champ d'expertise pointu :

l'apprentissage de compétence visant à opérer une machine complexe. En effet, les principes de transmission de compétence de pilotage ont longtemps été étudiés et résultent aujourd'hui en un cursus bien établi menant à l'obtention de brevet de pilote. De façon générale, ce cursus et les connaissances qui en découlent font maintenant l'objet de normes internationales édictées par l'organisation de l'aviation civile internationale et par les gouvernements. Ces normes sont constamment défiées par l'évolution fulgurante des technologies produisant des avancées qui appellent la communauté scientifique à évaluer et étudier ces progrès. Tout comme pour maints champs d'expertise, la venue de l'informatique a apporté aux sciences de l'apprentissage et de l'instruction une foule de considérations nouvelles et généré un paradigme propre à ce contexte. Le paradigme dont il est question dans cette étude sert de cadre conceptuel : La théorie cognitive de l'apprentissage multimédia (TCAM) (Mayer, 2014). Bien que l'apprentissage multimédia ait été possible par le passé, il est devenu omniprésent via la panoplie d'outils informatiques qui sont aujourd'hui indispensables dans notre vie quotidienne. La TCAM apporte plusieurs perspectives permettant l'évaluation efficace de la technologie dans un cadre d'apprentissage.

De façon générale, la théorie cognitive de l'apprentissage multimédia étudie les processus cognitifs sous-jacents à l'apprentissage dans le but de produire des heuristiques de conception de matériel éducatif. En d'autres termes, la TCAM cherche à faire comprendre aux éducateurs les processus cognitifs d'apprenants, lorsqu'exposés à du matériel multimédia dans le but de les aider à concevoir du matériel éducatif multimédia pertinent. On souhaite donc générer des recommandations pour favoriser les processus nécessaires à l'apprentissage et diminuer les processus superflus. La méthode issue de ces recommandations qui nous intéresse est le guidage de l'attention.

La technologie sur laquelle porte ce mémoire est l'utilisation du regard d'experts comme guide attentionnel dans un vidéo d'entraînement ou communément appelé *Eye Movement Modeling Example (EMME)* en anglais (voir Fig. 1). L'oculométrie est à la base de cette technologie en fournissant des capteurs qui enregistrent la position du regard sur une interface. Un enregistrement de la position du regard peut ensuite être représenté graphiquement et superposé sur un enregistrement de l'interface en question. Dans le cas présent, le regard est représenté par un cercle rouge superposé sur un enregistrement du poste de pilotage simulé. Cette technologie a été étudiée dans divers contextes pour transmettre ou entraîner des comportements visuels désirables, notamment dans la mécanique aéronautique, le contrôle aérien et la formation de pilotes experts. Bien que ces études illustrent un emploi pertinent de cette technologie dans un contexte aéronautique, la formation de pilotes novices serait une approche pérenne pour l'amélioration des compétences de monitoring de pilotes professionnels. La question se pose donc : Les pilotes novices bénéficieraient-ils de ce type de matériel de formation dans leur parcours?

Figure 1 *- Exemple d'utilisation du regard d'expert comme guide attentionnel (EMME)*

Note: Trois images extraites de la vidéo d'entraînement utilisée dans l'article empirique.
Dans la première image, l'expert regarde à l'horizon. Dans l'image 2, son regard se déplace vers l'anémomètre. Dans l'image 3, son regard se déplace vers l'altimètre.
Dans la vidéo, une trainée rouge suit la représentation de l'expert, ici représentée à l'aide d'une flèche rouge.

Objectif du mémoire

L'objectif de ce mémoire est d'évaluer la pertinence de l'utilisation du regard d'expert comme guide attentionnel dans un cadre de formation des comportements visuels efficaces de pilotes novices. Cette technologie sera évaluée par son impact sur les comportements oculaires en vol, par l'impact sur les performances de vol manuel et par la perception que les pilotes novices ont de cette technologie en action.

Structure du mémoire

Pour répondre à cet objectif, le mémoire est composé de deux articles.

L'article principal porte sur une expérience empirique effectuée auprès de 23 pilotes novices en simulateur de vol. Cette expérience expose des pilotes novices à une représentation du regard d'un expert dans un vidéo d'entrainement et mesure leurs comportements visuels à l'aide d'oculométrie. La question de recherche suivante guide cette expérience : *Dans quelle mesure l'exposition au regard d'un expert durant une vidéo de formation influence-t-elle les performances visuelles et les performances de vol manuel de pilotes novices en entraînement?*

Le deuxième article présente une synthèse des résultats du premier article sous forme d'article managérial. L'article discute de recommandations et constatations issues de ces résultats. Le niveau de vulgarisation de cet article vise un public professionnel plus large pour permettre une meilleure diffusion de la science à une plus grande échelle.

Contribution

Étant donné que ce projet de recherche a été conduit au sein du Tech3Lab, qui implique plusieurs collaborateurs contribuant au projet de mémoire à différents degrés, le tableau suivant vise à définir la contribution intellectuelle de l'étudiant. De façon générale, la contribution attendue des étudiants au sein des projets menés au laboratoire est d'environ 50%. Les dimensions pour lesquelles la contribution de l'étudiant surpasse 50% suggèrent l'initiative et l'autonomie de l'étudiant lors de la phase correspondante. La collecte de données s'est effectuée au cours de l'automne 2023 au Centre de Formation Aéronautique du Québec (CQFA), où l'étudiant a conduit le recrutement et la collecte de données.

Étape du processus	**Contribution**
Définition de la problématique	Définition de la question de recherche – 70% La question de recherche a été trouvée par l'auteur en collaboration avec la contribution de membres du Tech3Lab et des coauteurs de l'‘article empirique.
Revue de littérature	Effectuer les recherches pertinentes et rédiger la section de revue de littérature – 75% Certains articles fondamentaux au projet de recherche ont été recommandés par les directeurs et coauteurs de l'article empirique pour aiguiller le processus de revue de littérature. La première version écrite de la section de revue de littérature a été effectuée par l'étudiant puis révisée par les coauteurs.

Conception du design expérimental	Concevoir – 70% Le design expérimental a été conçu en collaboration avec tous les membres de ce projet en se basant sur la proposition de l'étudiant de concevoir une vidéo de formation impliquant une représentation du regard d'expert. Rédiger un Protocol expérimental – 70% La première version du protocole expérimental a été rédigée par l'auteur puis vérifiée par les coauteurs et des membres de l'équipe du tech3Lab.
Collecte de données	Recrutement de participants – 100% Le partenaire de recherche a entamé une recherche de participants qui s'est avérée peu fructueuse. La majorité des participants proviennent d'une démarche de l'auteur. Le Tech3Lab a conseillé l'étudiant sur certains aspects techniques du recrutement. Conduite de l'expérience en laboratoire – 100% L'expérience a été conduite majoritairement au Centre Québécois de Formation Aéronautique par l'auteur seul. Une partie de la collecte de données s'est déroulée chez CAE où l'auteur était également seul.
Extraction et transformation des données	Extraction des données pertinentes – 90% L'extraction des données a été conduite par l'auteur en fonction des recommandations du statisticien du Tech3Lab. Production d'un ensemble de données nettoyées pour l'analyse – 70% Le traitement des données a été fait par l'auteur avec l'appui du statisticien du Tech3Lab.
Analyse de données	Analyse statistique des données – 70%

	Les données ont été analysées en collaboration avec un statisticien du Tech3Lab. Interprétation des données – 70% L'interprétation des données d'analyse a été faite en collaboration entre l'auteur, les coauteurs et le statisticien du Tech3Lab.
Rédaction	Rédaction des articles du mémoire – 90% L'auteur a écrit les premières versions de l'ensemble du mémoire. Les coauteurs ont contribué à l'article empirique à l'aide de commentaires et l'écriture de quelques brefs extraits. Les codirecteurs de recherche ont apporté des commentaires pour l'ensemble du mémoire.

Chapitre 2
Is the exposition to expert gaze an efficient method of training visual behaviour of novice pilots?

François Cormier, Alexander J Karran, Constantinos K. Coursaris, Pierre-Majorique Léger and Sylvain Sénécal

Abstract

The goal of the current study is to investigate the efficacy of training novice airplane pilots via exposition to an expert's gaze. This novel training method known as eye movement modeling example (EMME) is closely related to visual behaviour and the corresponding literature hints at its potential value for pilots. The improper monitoring skills of expert pilots have been identified as an important cause of accidents by major organisations. This concern lead to the investigation of methods to minimize the associated risks with a variety of visual training methods. Literature and industry investigated multiple methods to train expert pilots, but a gap seems to persist in the visual training of novice pilots. Thus, EMME presents itself as a promising method of visual behaviour training accounting for the growing interest and availability of eye-tracking technology. To investigate this premise, a two-group between-subjects experiment was conducted with novice pilots in a commercial flight simulator. Both groups performed a first flight task, were then shown a training video, and subsequently performed a second flight task. The training video consisted of a recording of an expert's cockpit performing the same flight task. The video featured an audio narration providing instruction on proper visual behaviour. The training video was manipulated, displaying an expert's gaze representation overlaid on the video only to the experimental group. To measure the impact of this novel training method, participants' visual behaviour, manual flight performance and perceived utility value of the training video were analysed. Data was gathered for those analysis with an eye-tracker, telemetry data and questionnaires respectively. Results show that participants exposed to the expert gaze representation had significantly improved visual behaviour performance in certain flight segments and a significantly higher perceived utility value of the training video. Although the manual flight performance was not found to be significantly improved, the results of this study show value in the usage of the expert gaze representation in training videos.

Keywords : Eye-tracking, flight simulator, visual strategies, pilot training, manual flight skill, CTML, situation awareness, user experience, visual attention, expert gaze .

This article is in preparation to be submitted at the premier annual conference event of the Special Interest Group on Human-Computer Interaction (SIGCHI) .

2.1 Introduction

It has been said that vision is the most important sensory component of piloting (Gerathewohl et al., 1978). Today's aircrafts are increasingly complex systems requiring good monitoring for a large number of instruments, sensors, and indicators. Indeed, today's aircrafts are more autonomous, and the pilot's role has shifted from manual control to a system monitoring role. This monitoring role has different skill requirements than the more involved manual piloting, notably an increased monitoring requirement (Lerner, 1983) and can cause an overreliance on the system (Wickens et al., 2015). The increased automation in fact has an impact on situational awareness which requires a larger amount of effort to maintain proper awareness and a safe flight (Barladian et al., 2021). It is required of pilots to extract pertinent information and integrate multiple data sources relayed through the visual field into a situation awareness. This shift in pilot's role has had an impact on the observed cause of accidents and incidentally brought a response from the field.

The air transport field always had a strong consideration for safety. It still makes it one of the safest ways to travel to this day. The importance of safety brought with it rigorous norms of accident inspections, resulting in detailed findings and reports. Indeed, major aviation organizations have identified improper cockpit monitoring as a major cause of aeroplane safety incidents since the 1980s (United States National Transportation Safety, 1994). A study found similar results when applying their taxonomy of situational awareness errors. In fact, based on NASA's Aviation Safety Reporting System database (ASRS), Jones and Endsley (1996) report that 76.3% of the identified errors were identified as errors in perception of information (or Situation awareness Level 1). Of the total errors, Failure to monitor (information) accounted for 37.2% of all errors, validating the reports of organisations. Training pilots to better perform cockpit monitoring by adopting better scanning strategies was identified as one of the steps to minimize this problem (Abbott et al., 2013; I.A.T.A, 2016). For a pilot, visual scanning strategies pertain to optimizing fixation patterns that aim at monitoring the cockpit and the state of the aircraft to manoeuvre it towards desired attitudes (Lefrançois et al., 2021).

This increased awareness of visual strategies' importance has prompted the investigation of pilots' scanning strategies in flight and the optimal way to transmit desired strategies to other pilots (Adam & Condette, 2013). Although literature exploring visual scanning training for experts exists, few studies investigated the relevance of training visual strategies of novices. Previous studies regarding skill acquisition through training of efficient oculomotor behaviour show the benefits of such a method (Kimron L. Shapiro, 1989). In this fundamental study, they trained participants to efficient oculomotor strategies and found their performance in a mostly visual task (Video game) to be improved. A recent review on the use of eye movement modeling example reports a long pause in published literature between this fundamental study and more recent work (Tunga & Cagiltay, 2023) resuming around 2009 with the work of van Gog training oculomotor behaviour for a strategy game (van Gog et al., 2009). This method of oculomotor training has found success in various training or education areas including medical, geometry, business, and aviation. Two studies tested the value of showing an expert's gaze to novices aiming to induce better scanning strategies in non-pilots aviation professionals, namely air traffic controllers and mechanics (Sadasivan et al., 2005). Studies on training novice pilots' visual strategies through the imitation of an expert's gaze are lacking and thus the focus of this article.

A current gap in this body of knowledge is whether the efficacy of using expert gaze may also be realized in the context of training novice pilots. Hence, this research is guided by the following overarching question:

> **To what extent does the exposure to an expert gaze during a training video influence the visual behaviour and flight performance of novice pilots?**

An experiment was conducted to investigate this question. Novice pilots were recruited to perform simulator tasks before and after being exposed to a training video. Experts were recruited to generate footage and data to produce a training video and reference performance data. The training video was manipulated to include expert gaze representation in one of two versions of the video which was randomly assigned to half the participants. Visual behaviour, manual flight performance and perceived value of the training video were measured.

Our results show some clear improvements in the measurements of the visual behaviour and manual flight performance of novices. The experimental group's performance during the navigation phase was significantly closer to the expert's performance than that by the control group. The experimental group's perceived utility of the training video was significantly higher than that of the control group. As such, the present study contributed to the validation of the use of the eye movement modeling example (EMME) method in a pilot training context.

This article begins with a review of the literature in section 1.2 leading to the presentation of the hypotheses in section 1.3. The methodology of the experiment is presented in section 1.4 with the last section of the methodology describing the analysis method. Then results are presented in section 1.5 and results are discussed in section 1.6 before the conclusion in section 1.7. Appendix and references can be found at the end of the article in section 1.8 and 1.9 respectively.

2.2 Literature review

This literature review covers learning, visual behaviours training, and the specific context of piloting in order to frame the evaluation of a new method for producing educational material. Indeed, the context of simulator-based learning addressed first in this literature review introduces the cognitive theory of multimedia learning (CTML) which serves as a theoretical foundation for this study. From the vast field of CTML, the main interest of this study is the application of its guidelines to train visual skills which can trace the path to this study. To do so, the training of visual behaviour as well as the corresponding use of eye-tracking technology are discussed next. All this culminates in the presentation of the technology under study: the eye movement modeling example (EMME). For a deeper understanding, we cite two mechanisms by which EMME acts on the learning process. We establish the link between learning appropriate visual behaviours and pilot performance. Finally, a section on piloting sets out the different skills and performance measures that have been studied.

Training environment of pilots

Training pilots using flight simulation technologies is a well-established field of study, with proven benefits regarding the combination of simultaneous training using both simulators and aeroplanes (Hays et al., 1992). The rapid advancement and adoption of personal flight simulators have provided access to safer, more efficient, more environmentally conscious, and relatively low-cost methods to develop piloting skills or experience flight (Cross et al., 2022). Flight simulator use prior to flight training has also seen substantial growth in terms of use and research on this use case (Dennis & Harris, 1998; Macchiarella et al., 2006). Recent studies suggest that the use of simulation in *ab initio* pilot training always has a positive impact on safety and risk reduction. However, the data suggest caution for the simulation training integration as positive outcomes for training efficiency and cost-effectiveness are not always guaranteed (McLean et al., 2016). Therefore, the rigorous testing of training methods is of the utmost importance to promote all of the simulation's benefits.

Recent flight simulation software commonly provides exercises to familiarise users with general aviation. These exercises are closely related to e-learning. That is, they are performed outside of a traditional flight school and without the intervention of a flight instructor. One main concern with such hands-off training is the very strong motivation and time management skills required to overcome the lack of interaction and learning dynamics associated with traditional learning places which can lead to insufficient use and deficient results (Alenezi, 2012; Tarhini et al., 2014). According to the CTML, motivation also plays a role in fostering generative cognitive processes thus promoting better learning (Richard E. Mayer, 2014). Motivation has also been identified as an indicator of pilot training outcomes (Zierke, 2014).

The modern training environment of pilots makes great use of the technology with ever more accessible and performant simulators. Although those are great tools, they require equally great care in the conception of training content to ensure high motivation and great results.

Cognitive theory of multimedia learning (CTML).

Today's skill learning, similarly, to education, is intertwined with technology. This omnipresence of technology needs to be taken into consideration when creating training material or elaborating training programs. To investigate the use of novel technology in the context of pilot training, the framework provided by the cognitive theory of multimedia learning presents itself as a natural choice. The CTML is an applied perspective to learning theory aiming to provide guidelines to educators on the development of educative material based on the cognitive activity of learners (Mayer, 2008). The CTML is based on the monitoring of three cognitive processes categories: essential, extraneous, and generative. The way by which the resulting guidelines aim at improving learning is to manage essential processing, reduce extraneous processing and foster generative processing (Moreno & Mayer, 2010). Monitoring cognitive processes during learning is a complex task and was most frequently accomplished by self-reported measures, clinical interviews or behavioural assessment procedures often associated with validity issues (Rodrigues & Rosa, 2019). The presence of those effects always puts a risk of validity fault when using self-reported measures and calls for alternatives or complements to generate behavioural data. Modern eye-tracking technology provides a method to gather data unobtrusively and objectively, supporting self-reported and interview methods. The cognitive theory of multimedia learning (CTML) which investigates instructional material consisting of multiple representations (Mayer, 2014) with the increase in availability of eye-tracking technology generated some interest in the training of efficient oculomotor behaviour.

Visual skill training and Eye movement modeling example (EMME)

Visual training is a sought-after way to interface with the brain and the sensory system whether it be in the context of health rehabilitation (Bouwmeester et al., 2007; Pambakian et al., 2005), remediation of disabilities (Metzger & Werner, 1984), athlete performance (Hüttermann et al., 2018) or skill training (Anastakis et al., 2000). In the case of skills training, the benefit of training efficient oculomotor behaviour to enhance skill acquisition has been found to have a significant benefit in the context of a video game (Kimron L. Shapiro, 1989). In fact, in a shorter timeframe, it allowed subjects to develop oculomotor patterns which would have eventually developed with the repeated exposition to a stimulus. Even though those benefits were found, research was limited mostly to reading and has only seen increased interest in more general learning research in the first decade of the century (van Gog et al., 2009). At the time, eye-tracking technology got modernised and allowed for recordings to be made and for it to be integrated with interactions of participants with computers. This prompted research on its usage not only as a measurement tool but as a tool to produce or enhance learning materials. This novel usage of eye-tracking technology in literature has mainly been investigated through the point of view of the instruction sciences. With its type of content being fundamentally multimedia, the theory of cognitive multimedia learning provides a strong conceptual framework to investigate the value of this technology.

The development of eye-tracking technology as a means to explore cognitive abilities allowed a finer analysis of participants' visual behaviour when exposed to multimedia content (Alemdag & Cagiltay, 2018). Eye tracking can be used to produce precise recordings of eye- movements, which allows the investigation of new training methods, namely a method of operationalising gaze heuristics as an attentional guide and learning tool. This novel type of multimedia learning tool, first developed in the work of van Gog et al. (2009) and later known as Eye Movement Modeling Examples (EMME), are type of video modelling example containing additional eye movement recordings of the model to provide attentional guidance (Tunga & Cagiltay, 2023). This additional eye movement recording is being displayed as a moving visual representation of the gaze (See Figure 2). Various parameters exist in the literature to define the best type of representation (e.g., the effect of size, colour, and shape of gaze representation), but the bulk of the literature is focused on the relevant contexts of use. EMME is based on the signalling principle which states that adding signals to important parts of training material guides learners' attention leading to better learning (Van Gog, 2014).

Figure 2 *- Example of a gaze representation*

Note: In the first frame, the expert gazes at the horizon represented by a red circle.
In frame 2 the saccade in the expert's gaze is shown as a line towards the new fixation of the anemometer.
In frame 3 the saccade in the expert's gaze is shown as a line towards the new fixation of the altimeter.
(The arrowhead at the end of the lines as well as the transparent fixation in frame 2 and 3 were added for clarity in this figure)

Training methods similar to EMME videos but not identified as such were investigated in the aviation field. A previous experiment trained air traffic controllers experiment exposed novices by exposing them to a video of a work interface overlaid with an expert's gaze representation as a training method to improve scanning strategies (Kang & Landry, 2014). The training aimed to improve the performance of novices in a conflict detection task. The study found that novices exposed to the expert's gaze had significantly better performance measured in terms of false alarms when compared to the control group. The participants also responded that the expert's path helped them perform better.

A similar study showed a composite of an expert's gaze in a head-mounted display to train novice aeroplane mechanics to perform visual inspections (Sadasivan et al., 2005). In that study, participants benefited from feedforward training, meaning they were given information about existing defects prior to the inspection task. Feedforward training in this context helped participants to contextualize the expert's gaze scanning patterns. The representation was also user paced as opposed to a continuous video. Representation of gaze length was displayed next to the expert gaze location. The study found that participants performed a subsequent inspection task slower than the control group but exhibited better scanning strategies and better defect detection performances.

EMME training has recently been applied and investigated in a study on the training of airline pilots' visual scanning (Lefrançois et al., 2021). In this study pilots completed multiple simulated landing approaches in a multicrew setup, first to gather baseline data and then 10 months later to train them. The experimental group were trained via feedback on their performance as well as EMME from the most accurate pilots recorded in the first. The control group received general guidelines on cockpit monitoring. The study reports results both in terms of operating (i.e., manual flight) performance in terms of vertical and lateral deviation and in terms of visual behaviour. Vertical and lateral deviation decreased significantly more for the experimental group and the efficient scanning patterns of the most accurate pilots were found most frequently in the experimental group. Those results show an increased similarity of the experimental group's performance with the most accurate pilots' performance, indicating improved performance in all measured aspects.

Mechanism of learning with EMME

EMME is a novel way to apply principles issued from the sciences of instruction and learning. The cognitive theory of multimedia learning can help us link the cognitive process to eye movement but to have a better understanding of the actual cognitive processes, Bandura's social learning theory helps complete the picture.

In this fundamental theory of psychology, the learning process was defined as both a social and cognitive process (Grusec, 1994). This novel approach was a departure from earlier theories of learning limited to stimulus-response. The social aspect of learning originated from the conception that learning in humans could happen by mere observation. A famous yet controversial series of experiments set out to validate this principle by exposing children to an adult model acting aggressively towards a Bobo doll and evaluating their behaviour when left alone with the doll (Bandura et al., 1961). From then, the concept of modeling was refined to consider different types of modeling stimuli as well as cognitive mediators, namely: attention, retention, reproduction and, motivation. The eye movement modeling example (EMME) is taking basis in the principle of modeling observed behaviour as a way of learning, as its name implies. The novel factor comes from the fact that this behaviour is not naturally observable by humans, we cannot infer gaze position from looking at another person's eyes. Although some research on EMMEs are diverse in their aims and practices, the applied characteristics of a pilot's monitoring skill emphasise the benefit of imitation present in EMME as opposed to a more abstract skill like classroom problem solving (Wright et al., 2022). In fact, monitoring a cockpit is a skill that relies on proper and consistent attention allocation, a process that is both cognitive and physiological for which traditional methods were limited in the represented model they could present learners (Sumwalt et al., 2015). When considering this theory, we would expect pilots exposed to the visual representation of gaze to have improved learning of those behaviours as well as a more frequent display of imitation.

The second method by which EMME impacts learning is conceptually closer to the majority of the literature on EMMEs: attention guiding. CTML builds on the notion that the creation of links between multiple elements, a process required to learn, requires a whole process of selection, organization and construction of links with prior knowledge which is not possible if said elements are not present in the working memory (Jamet et al., 2008; Mayer et al., 2001). This process can be supported in a variety of ways to produce a better integration of knowledge and result in better learning. The common classroom help illustrate the modality principle of CTML where a teacher speaks while students are looking at visual information through a textbook. In this situation, the students can have both representations active in their working memory and, with less effort, create links leading to learning. In this case, cognitive load is lowered by utilising two processing channels: visual and auditive. While this method is effective, it does not help to assimilate information that has an inherently high cognitive requirement like complex visual representations in the form a diagrams or in our case a cockpit. The guiding principle states that by signaling parts of a visual learning component to the learner, extraneous cognitive load caused by task-irrelevant scanning can be lowered, effectively increasing the cognitive resources available to be allocated to processes fostering better learning (Jamet et al., 2008). Thus, we would expect the representation of an expert's gaze to facilitate the process of finding visual areas described by the audio narration, lowering the cognitive load necessary to follow the instructions and improving the integration of the instructions.

Visual behaviour and its relation to Situation awareness (SA)

Situation awareness has been described as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988). In fact, it is a crucial part of the pilot's tasks required to maintain a safe flight. Pilots need to have appropriate awareness of the evolution of their aircraft in space and time to take appropriate decisions and perform safe manoeuvring at all times. The characteristics of the flight environment are what create this necessity of maintaining proper awareness: it is a complex system in a dynamic environment (Uhlarik & Comerford, 2002).

Endsley's definition introduces the three levels of SA according to his model. The first level pertains to the perception of information or the various ways in which a pilot might actively gather information. This perception applies to all the instruments and other indicators in the cockpit but also refers to the further information a pilot might need like window view, or the various sounds produced by the plane or a malfunction. The second level of SA is the comprehension of the perceived information. In the first SA level, information might be perceived and retained but is not fully integrated into a comprehension of the situation. A simple example is the processing of the perception that a warning light is on into a comprehension that it is representing a critical system failure. The third level of SA is the projection of the current actions, state, and elements of the environment into the future. The ability to project into the future is essentially what lets a professional pilot anticipate outcomes and provides the basis for the selecting a course of action.

Although individual differ in their innate ability to acquire and maintain SA, differences in equipment and training also influences the cognitive effort required to produce a certain level of awareness (Endsley et al., 2007). In fact, some of the underlying skills required to produce adequate SA have been found to not be trainable (Endsley & Bolstad, 1994). The selection of piloting candidates needs to consider those discrepancies in the abilities of individuals. Once adequate candidates are retained, appropriate training needs to be conducted to take advantage of internal mechanisms allowing lower cognitive load requirements for SA. Endsley identified three major coping mechanisms pilots use to facilitate SA: Mental models, Goal-driven processing, and Automaticity.

The role of visual behaviours of pilots is closely related to the first level of SA. This first level of SA has been a common cause for accidents across the air transport industry as identified by Endsley's taxonomy of situation awareness errors (Endsley, 1995). Visual behaviour of pilots is the first requirement of situation awareness by providing raw information that pilots can then interpret to take decisions. According to the model of pilot's situation awareness, training performant visual behaviour of pilots would address the most common skill shortcoming and generate the biggest improvement in human factors of air transport safety.

Piloting skills

With the training of novice pilots as the focus of this study, the definition of desirable skills is mandatory. While situation awareness is a crucial skill as mentioned above, it mostly contributes to the decision making. Pilots need to physically perform multiple tasks including manual manoeuvring of the plane as well as visually scanning the instruments. Measuring those actions with modern technology is accessible with an ease and unobtrusiveness that mental processes measurements do not permit. Thus, this section discusses the literature relevant to the skills and actions performed by pilots as well as the measurement and evaluation of those performances.

Visual performance

Research shows that visual behaviour training is a promising way to improve piloting skills efficiently (Haslbeck et al., 2012). The majority of a pilot's attention when flying a plane is divided between the manual handling and the monitoring of the cockpit, and this division will vary depending on the flight regime and the ability of the pilot (Di Nocera et al., 2007). Depending on the flight regime, a larger proportion of the pilot's attention will be directed toward one of those two activities. Although modern aviation is increasingly reliant on automation, pilots' instrument scanning and manual control skills have been found to remain mostly intact even after infrequent use and application (Casner et al., 2014). These findings indicate that novices might benefit from learning visual behaviour like expert pilots performing manual control flights in a similar context.

Eye-tracking has been reported extensively in the literature as a means to evaluate pilots' expertise and the relationship between the expertise, ability to manoeuvre an airplane and visual behaviour were all strongly correlated (Haslbeck et al., 2012; Lounis et al., 2021). Utilising this technology, two main types of measurements of eye movement are used: fixations and saccades (van Gog et al., 2009). Saccades are rapid movement of the eye observed when the fovea is being repositioned to a new location in the field of view. Fixations are the stabilisation of the fovea on a target of interest (Duchowski & Duchowski, 2017). Fixations can be interpreted as the moment the eye is taking in visual information from the area.

Many metrics developed explicitly for evaluating pilots' performance (Glaholt, 2014) have been derived from saccade and fixation data (Holmqvist et al., 2011). Eye movement measures fall mainly, but are not limited to, two categories, dwell analysis and patterns analysis. In the context of a cockpit, analysing the dwell location and duration helps to understand the relationship between visual areas in terms of frequency or total information gathered. Proportional dwell time, number of fixation counts, and proportional fixation time are all examples of metrics directly representing a quantitative indicator of how much or how frequently the pilot gathered information from a zone. Analysing gaze patterns can inform researchers about users' high-order patterns. Measuring transition entropy is one of the possible metrics which produce a value representing the extent to which the dwell sequence is disordered or random. In their analysis of such measures, Lounis et al. (2021) found that gaze transition entropy, amongst others, was a valid method to follow the development of visual scanning strategies of novices and to detect their similarity to strategies observed from experts.

Flight performance

Manual flight performance is the main control by which the pilot can operate the aircraft. The terms operating performances and manual flight performances are used interchangeably to describe the manual control of the plane by the pilot using flight controls. The two main approaches to evaluating manual flight performance are certified flight instructors' evaluation and statistical flight telemetry analysis(Haslbeck et al., 2014; McClernon & Miller, 2011). The certified flight instructor evaluation is the most generalizable approach between the two as it is directly using flight examinators of the corresponding jurisdiction. Although the resulting evaluation can be directly translated to the expected performance of flight exams, it requires a qualified professional. On the other hand, telemetry analysis is often used to emulate this expertise or to provide additional objective measurements, while using the statistical knowledge that is much more likely to fall in the research's team expertise.

Skill evaluation for pilots mainly comes from the private and commercial pilot licence exam. The pilots' evaluation guidelines primarily address procedures and decision-making. Whereby manual flight performance is evaluated through general guidelines related to flight smoothness or precise flight parameters range. The numerical flight parameters are mostly associated with pass-or-fail manoeuvres. When looking deeper into the evaluation of flight smoothness, the guidelines mostly include subjective evaluation based on the examinator's expertise. For Transport Canada, this subjective evaluation falls under airmanship: "*The candidate will be expected to demonstrate good airmanship and complete accurate checks on a continuing basis and demonstrate the smooth and coordinated use of flight and power controls"* (T.C., 2010). Other notable aviation organisations have similar flight smoothness defined in the evaluation of pilots' flight performance; IATA mentions the flight path management as one of the basic elements of monitoring intended for training program creation as "Controls the aircraft using automation with accuracy and smoothness as appropriate to the situation" (I.A.T.A, 2016).

The previously cited examples above appear to have adapted objective flight smoothness indicators based on simple variance analysis of parameters available in their telemetry. Some parameters can be evaluated as being impactful for flight smoothness with the basic assumption that changes in aircraft state should not be sudden. As such, bank, pitch, course deviation and operator input are great candidates for a simple evaluation of flight smoothness with statistical analysis of variance (McClernon & Miller, 2011).

In sum, the current review of the literature leads us to the use of two main measurement methods: eye-tracking and telemetry. The former is a direct response to the report that the lacking visual skills of professional pilots are causing accidents. The lack of literature concerning the training of novices' visual behaviour provides a great question to which this study wishes to contribute. While the use of telemetry is less of a crucial measurement tool, it provides a more complete picture of the performances that novice pilots will face as license exams.

2.3 Hypothesis development

Novel training methods such as eye movement modeling example (EMME) have been the objects of studies on the improvement of the underlying processes of skill learning (Tunga & Cagiltay, 2023; Xie et al., 2021). The CTML provide guiding principles which give researchers and training content producers a better overlook of the possible method to foster cognitive processes beneficial to skill learning (Mayer & Moreno, 1998). In the case of this study, the usage of EMME is being investigated with the signaling principle as the supporting guideline for learning content improvement (Jamet et al., 2008; van Gog et al., 2009). This principle aims to reduce extraneous cognitive processes by directing the learner's attention with a signal, in this case, the expert's gaze representation (Mayer, 2014). This better integration is caused by the increased available cognitive resources to dedicate to learning (Mayer, 2008). Another seemingly important mechanism of EMME learning in the case of pilots' visual skill according to the social learning theory is the representation of a previously unobservable behaviour. This creates a reference for novices to exhibit imitation behaviour, in turn leading to learning and integration of observed skills (Grusec, 1994). The existing literature on EMME has reported the benefits of this method in various contexts and skills being learned (Tunga & Cagiltay, 2023). In the case of pilots, learning efficient oculomotor behaviour is a crucial part of generating appropriate situation awareness to maintain safe operations (Lefrançois et al., 2021). Additionally, the fact that novices are seldom taught about visual strategies provides a significant opportunity to impact the acquired visual skills in pilot training programs.

> **H1:** Novice pilots exposed to an expert's gaze representation through an eye movement modeling example (EMME) during a flight training video will exhibit a significantly closer imitation of observed behaviour than trainees who are exposed to the same training video content without the EMME.

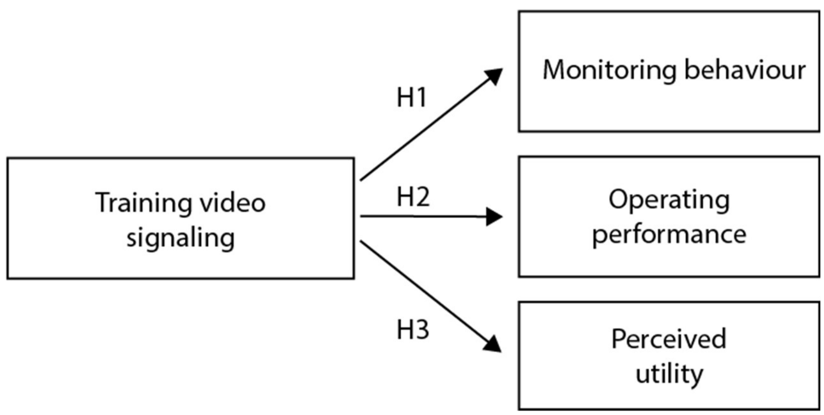
As described in the literature, manual piloting skills are somewhat dependent on the attention a pilot can allocate to flying the plane (Haslbeck et al., 2012). This attention requirement is a direct function of the attention given to proper monitoring which can be trained by visual behaviour training (Lefrançois et al., 2021; Lounis et al., 2021). Indeed, training pilots to better visual behaviour has been found to improve manual flight performance (Lefrançois et al., 2021). A more efficient monitoring of the plane is thus expected to lead to better flying performances (Haslbeck et al., 2014). This expectation coincides with the expected imitation behaviour described for our first hypothesis. The presence of visual behaviours that are similar to experts should represent an improvement in scanning behaviour of novices. As such, we would expect an improvement the visual behaviour to result in a manual flight performance. We, therefore, propose the following hypothesis:

> **H2:** Novice pilots exposed to an expert's gaze representation through an eye movement modeling example (EMME) during a flight training video will show improved operating (i.e., manual flight) performance compared to trainees who are exposed to the same training video content without the EMME.

The experience of the learner is another important aspect of testing the efficacy of training content (Borah, 2021; Wang et al., 2008). Training content needs to foster the appropriate cognitive processes but additionally, it must support learner motivation. Motivation is a crucial factor in the success of a training program and more so in the context of e-learning where support has a smaller impact and where abandoning a program has fewer impediments (Wang et al., 2008). Motivation in pilot training just as general learning and skill training has been linked to successful training program outcome (Zierke, 2014). In turn, a main criterion impacting motivation in the case of e-learning has been found to be the perceived value of the training program by the learners. A higher perceived value leads to higher motivation, which in turn has been linked to higher success rates (Abdullah & Ward, 2016; Abdullah et al., 2016). A novel training method has the potential of being perceived as valuable by the participants, providing additional motivations to complete a training program. We expect the proposed modification of training videos, the overlay of an expert's gaze representation, to generate a higher perceived utility by the learners (H3). We thus propose the hypotheses:

H3: Novice pilots' perceived utility of a flight training video will be significantly higher when exposed to a version of the training video featuring an eye movement modeling example.

Figure 3 *– Research model*



2.4 Methodology

Research design

We designed a between-subjects study with a flight simulator to measure the effects of exposure to a training video either containing or not an expert's visual scanning behaviours on novice pilots' visual behaviour, flight performance, and perceived utility of the training video.

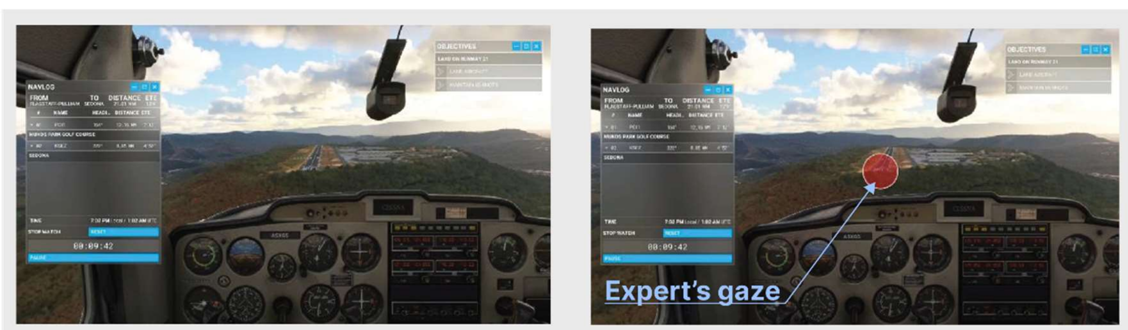
The tasks consisted of performing two full-length pre-determined flights in a flight simulator and watching a training video in-between the two flights. Both flights included a takeoff, departure, navigation, arrival, and landing phase. After the first flight task, participants watched a training video on proper visual behaviour in flight.

Participants were randomly assigned to one of the stimuli conditions. After completing both tasks, participants were asked to complete a psychometric battery and were interviewed.

Stimuli

Two identical training videos (see Appendix #1 and 2 for the narration script) were made to both provide training on visual behaviour through audio narration and a recording of the simulated cockpit of an expert's performing a flight task. In the manipulated version of the video, the gaze behaviour of the expert performing the second task was overlayed over the video recording, to apply the EMME method (see Fig. 4). This overlay serves as a means to signal the training content, guiding the participants' attention towards the area they should be looking at or in this case, towards the gaze location of an expert. This signaling principle is stemming from the guidelines of the CTML (Mayer, 2008).

***Figure 4** – Screenshots of the training video*



Note : Two screenshots of the training video. Control video without expert gaze representation (Left) Manipulated version with expert gaze representation (Right).
See appendix #3 for additional screenshots

Sample

A total of 23 participants (6 female, avg. age = 22 ± 4) were recruited from within an aerospace company and a public flight school (avg Flight Time = 36.57h). This experiment got the approval of our institution's board of ethics (certificate number 2023-4954) All participants signed consent in accordance with the research ethics board of our institution; no compensation was provided for participation. Licensed private or commercial pilots were disqualified from the recruitment.

Additionally, two expert pilots were recruited to gather reference data and footage from performing the same tasks as the participants. Both were active, licensed airline transporter pilots (avg Flight Time =

3200 h). The experts signed a consent form and completed the tasks with the same simulator equipment and setup as the participants.

Experimental procedure

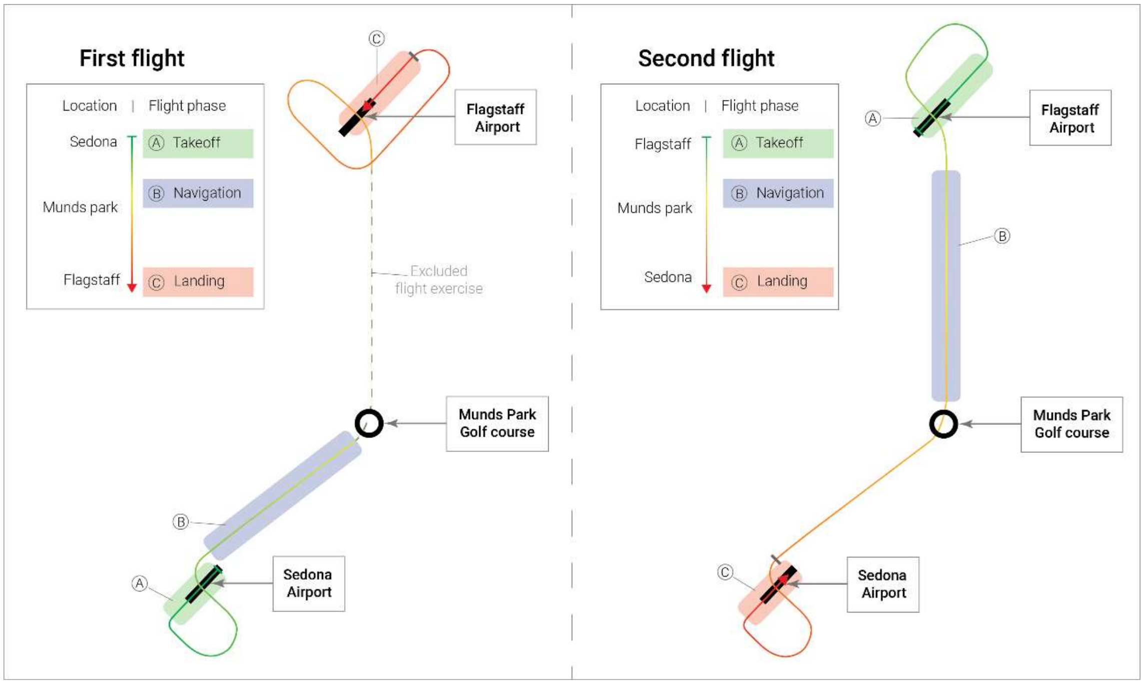
The experiment was conducted in Microsoft flight simulator (Asobo, 2020). The tasks chosen are from a series of visual flight navigation exercises included with the base software. This series is made up of two main portions which were used respectively for the first flight task (pre-treatment) and the second flight task (post-treatment). The first flight task aims at gathering baseline data to allow for the testing of potential improvements in monitoring and operating (i.e., manual flight) performance.

The first portion of the series, representing the first flight task in this study, recreates a navigation training flight with instructor (See left side of Fig. 5). The virtual instructor gives audio directions to help navigate and track exercise objectives displayed in the UI. It does not give feedback on flight manoeuvres and provides no information that cannot be seen in the UI. In the software, this first portion is divided into four parts where the flight is interrupted when an exercise end (departure procedure, navigation, arrival procedure and landing) and resumes at a set position for the next exercise. All exercises start approximatively at the same position the last one ended, forming a complete journey. The third exercise in this portion was excluded from the experiment because the objectives required camera movement which would have interfered with AOI analysis (See dashed line segment in flight 1, Fig. 5).

The second portion of the navigation exercise series, representing the second flight task in this study, recreates a first solo navigation flight (See right side of Fig. 5). The path taken is the return flight of the first portion. The virtual instructor is absent for this portion. Participants are provided with the same amount of visual help and information by the software but without the audio narration of the virtual instructor. This portion is not divided into exercises and forms a complete flight without interruptions.

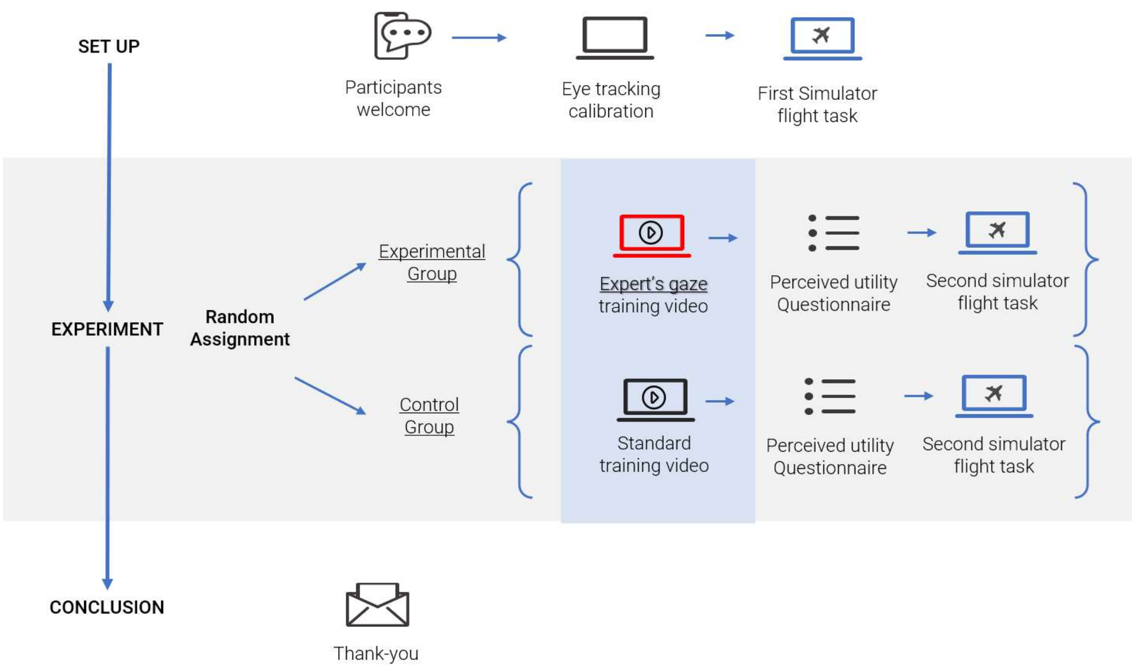
Both portions start with a takeoff and departure procedure, followed by a navigation exercise to reach the arrival aerodrome, and both end with the arrival procedure and landing (see Fig. 5).

***Figure 5** - Simulated flight paths*



Before the first flight task, participants completed a consent form and a demographic questionnaire (see Fig. 6). They were then provided with an explanation of simulator controls. Participants were required to read the provided instructions before each task. After the first flight task is completed (avg. = 25 min.), they viewed the version of the 10 minutes training video that corresponded to their randomly assigned group, more specifically the experimental group saw a signaled video including the expert gaze representation while the control group saw a version without signaling. All participants were informed that the video aims to train visual scanning strategies and that it consists of footage of experts completing the flight task they will be doing next. Additionally, the experimental group were informed that the video included a representation of the expert's gaze. At the end of the video, participants completed a perceived utility questionnaire on the iPad (Apple Inc). Then the second flight is performed (avg. = 25 min.). The experiment ends with a short open-ended interview.

Figure 6 - Experimental Procedure



Equipment

Participants were seated at a desk approximately 70cm in front of a flight control system (TurtleBeach VelocityOne™ Flight Universal Control System and Logitech Flight Rudder Pedals) facing an ultrawide LCD monitor with the effective resolution set to 1080p widescreen (see Fig. 7). Video signal and was split into two parts to allow for researcher control during setup, training video display and during inter-trial pauses to administer online questionnaires. The flight control system was in a single-engine plane configuration comprising a yoke, pedals, trim wheel and levers for throttle, mixture and flaps mimicking the controls of the simulated airplane. Additionally, an in-simulator camera was fixed to allow for areas of interest (AOI) to be derived from within the simulated cockpit. Microsoft Flight Simulator 2020 (Asobo, 2020) provided the flight simulation and graphical display. Flight telemetry was provided using Flight Recorder (Hy, 2022), a 3rd party application. This application populates a data table with 70 flight telemetry values, and displays the telemetry variables derived to perform the performance analysis for this study. Eye-tracking data was captured and processed using a Tobii pro nano (Tobii Technology, Danderyd, Sweden) at 60hz and Tobii pro labs software respectively. Questionnaires were hosted on the Qualtrics online platform and administered during inter-trial pauses via web browser on an iPad (Apple, Cupertino, USA).

Figure 7 - *Experimental setup*

Note : Participant's point of view of the experiment setup (Left)
Researcher's point of view of the experiment setup (Right)

The training video displayed to participants during the inter-trial pause consisted of excerpts from the experts performing the second flight task recordings with an audio explanation of desired visual behaviours. The script of this audio narration was written using reference training material provided by Transport Canada and the Civil aviation authority of Australia (Australian Government Civil Aviation Safety Authority, 2023; I.A.T.A, 2016; T.C., 2004). Video footage was then selected amongst the two experts' recordings to represent the text better. A licenced professional pilot made this selection.

Measurement

Measurements were made to analyse visual behaviour, operating (i.e., manual flight) performance and perceived utility. Visual behaviour was measured with gaze data recorded by the eye-tracker. Manual flight performance was measured with telemetry data recorded with the Flight recorder software (Hy, 2022). Perceived value data was self-reported in an online questionnaire administered to participants between tasks. Measurements were also made during the experts' flight tasks to gather reference data for visual behaviour and manual flight performance. Gaze data was collected continuously for the duration of the experiment. The data was labelled to match flight phases and experimental tasks. Telemetry data was recorded during flight tasks. Gaze and telemetry data were synchronised for every flight phase.

Table 1- Measurements

Raw data	Tool	Measurement	Values	Parameters	Signification
Gaze	Tobii pro nano	GTE	Higher values mean randomness or complexity. Lower values mean simple or predictable patterns of gaze transition[1].	Gaze transitions between AOI	Predictability of gaze sequence
		Fixation per AOI	Percentage of total fixation time of corresponding segment, Higher values means more allocated attention.	Altimeter	Instrument indicating altitude
				Anemometer	Instrument indicating speed
				Compass	Instrument indicating magnetic heading
				Heading indicator	Instrument indicating gyroscopic heading
				Turn coordinator ball	Instrument indicating turn coordination
				Side window	Lateral window of the airplane
				NDB	Unused navigation instrument
				Nav log	Software UI indicating flight information
				Windshield	Front windshield of the airplane
				Tachymeter	Instrument indicating engine's RPM
				VOR	Unused navigation instrument
Telemetry	Flight recorder	Flight smoothness	Total value range of parameter in a segment. Lower values means smoother flight.	gForce max range	Acceleration felt by the aircraft
				Heading max range	Compass direction of the aircraft
				Pitch max range	Rotation around the side-to-side axis
				Bank max range	Rotation around the front-to-back axis
Questionnaire	Qualtrics	Perceived utility	Self-reported measures of agreement with a statement on a 7 point likert scale. Higher means higer perceived value[2].	Usefulness (3 statements)	Perceived usefulness of the video on pilot training [2]
				Efficiency (3 statements)	Perceived efficiency of video at training a skill [2]
				Satisfaction (3 statements)	Statisfaction of watching the training video[2]

Note : [1](Krejtz et al., 2015)

[2](Abdullah et al., 2016) See **Table 2** for Perceived utility statements

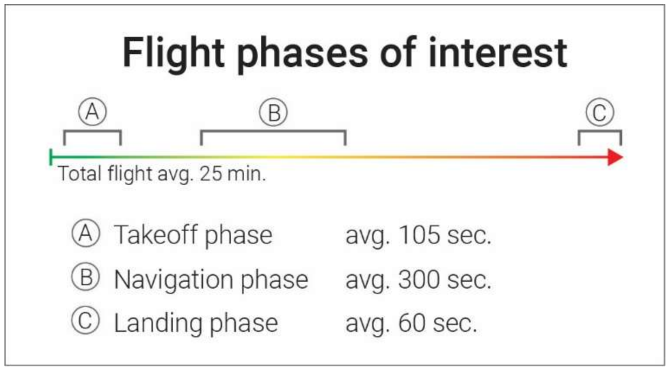
Postprocessing

After aggregating and collating the data, one participant's performance data was removed due to a software error, and two participants' pupillometry data was lost due to hardware failure leaving pupillometry data for 21 participants and performance data for 22 participants. All participants' questionnaire data was collected successfully.

Time segmentation

To limit the analysis to relevant and comparable flight segments, three flight *phases* of interest present in both flights were derived from the collected data: takeoff, navigation (rectilinear level flight) and landing. Those three flight phases of interest are present in both flights. Moreover, each flight phase is observed as two segments, one segment for each flight performed by the pilot; for example, the Takeoff phase is observed as Segment 1 during Flight 1, and again as a separate segment during the second flight. There are six flight segments in total. All the segments used for analysis are expected to be rectilinear flights with minor and/or progressive changes in altitude, pitch, and speed. This division results in a total of six analysed segments comparing three phases of flight over two subsequent flight tasks (see Fig. 8).

Figure 8 - *Flight phases of interest*



Phase beginning and ends were systematically identified to synchronise all data types using visual or parametric cues from the recordings. For the takeoff, the phase begins the moment the wheels stop touching the ground and ends at the first deliberate turn. The landing phase is identified the same way: from after the last deliberate turn in the direction of the runway until the moment the wheels touch the runway. The first navigation segment begins and ends when the aeroplane enters a radius from the simulations' objective landmark. The radius corresponds to the approximate minimum distance from a location required by the simulator to complete a positioning objective in-flight. This approximation results in a value of about 0.001 decimal degrees or 111 m which was obtained by comparing gaze recordings with telemetry data. The second navigation segment is 4 minutes long ending when the aeroplane enters a certain radius from the simulations' objective landmark.

Areas of interest

To quantify gaze behaviour in relation to cockpit components, areas of interest were used. In the context of eye-tracking research, areas of interest (AOIs) consist of bounded zones corresponding to a feature in the studied display. The AOIs used for analysis were derived from the simulated cockpit and the software's user interface (see Fig. 9). The following instruments each represent a distinct AOI: anemometer, turn coordinator ball, artificial horizon, heading indicator, altimeter, vertical speed indicator, VOR (*VHF omnidirectional range*), NDB (*Non-directional beacon*), Tachometer and compass. The front and side windshields both account for a distinct AOI. The software UI gives information pilots would normally acquire by referring to previously taken notes on a physical notepad, Air traffic controller communications or communication with their flight instructor and the corresponding AOI are the Navlog and the objective window.

Figure 9 - *Areas of interest*

Note : Screenshot of a participant's recording in Tobii Pro labs. Areas of interest are identified with different colors.

Visual Behaviour

The gaze data was first processed to create a fixation dataset. This process was the result of simplifying the dataset using the Tobii pro labs identification of gaze type and the defined AOIs. For every data entry (every 0.016ms.) gaze was identified as one of 4 types: Fixation, saccade, eyes not found and unidentified. Saccades, eyes not found and unidentified were associated to a null AOI. Some fixations were recorded outside of the identified AOIs, meaning that participants fixated on the cockpit between instruments or on the communication instruments which were not identified as AOIs. The proportion of null AOIs fixations was negligible. The data entries that recorded a fixation inside an AOI were the main interest of this analysis. To provide numerical values for comparison of visual behaviour, we calculated proportional fixation time per AOI (%AOI) and Gaze transition entropy (GTE) from the gaze data.

Proportional fixation time per AOI was calculated for each AOI from the total fixation time per flight segment. The resulting values represent the proportion of time allocated to fixating a single AOI.

The measure of Gaze Transition Entropy (GTE) was derived from the gaze data and the AOI (Shannon, 2001; Shiferaw et al., 2019). This approach allows the measurement of the extent to which the temporal sequence of eye movements is ordered or random during a flight training exercise.

Entropy is a measure of a lack of predictability in a gaze sequence; this metric enables the evaluation of structure within the gaze of a pilot. When applied to eye tracking data, gaze transition entropy describes the amount of information required to describe the visual strategies followed by pilots and is computed following the formula:

Equation 1 *- Gaze transition entropy*

$$H(x) = -\sum_{i=1}^{n} p_i \sum_{j=1}^{n} p(i,j) log_2 p(i,j)$$

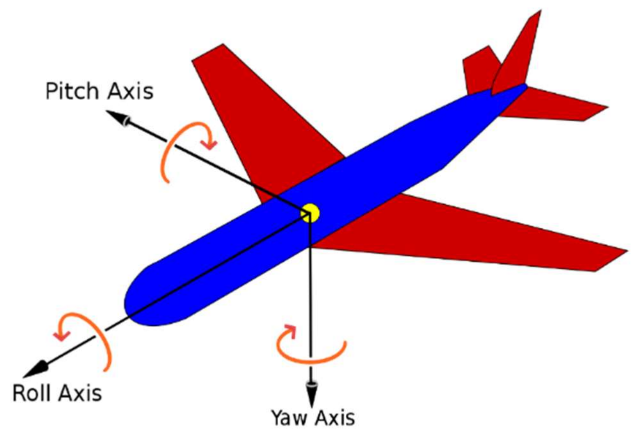
Where *i* represents the "from" AOI and j represents the "to" AOI. Higher transition entropy values denote more randomness and frequent switching between AOIs (Krejtz et al., 2015). Increases in GTE were noted during an experiment that manipulated pilots' cognitive workload through the addition of secondary tasks (Ephrath et al., 1983). Additionally, it has been reported that entropy increased as a result of cockpit instrument failure, conditions that most likely produce an increased mental workload (van de Merwe et al., 2012). More recently, the use of GTE as a metric to measure scan sequence predictability revealed that GTE was shown to significantly decrease when trained pilots faced a scenario presenting more task complexity and thus involving a more deterministic scanning behaviour (Diaz-Piedra et al., 2019). We, therefore, use GTE in the current case to determine the variation in gaze scan patterns between both groups and after viewing the training video with an expert's gaze patterns overlayed.

Operating performance (Manual flight performance)

Flight telemetry was recorded with a 3rd party tool to provide data on the airplane's behaviour. This tool produced a detailed recording of over 70 parameters every 0.0166ms. Recorded parameters fall under many categories: *control position parameters* (aileron position, elevator position, rudder position, elevator trim position, throttle lever position), *aircraft position parameters* (altitude above sea level, latitude, longitude), *indicated aircraft attitude parameters* (gyroscopic heading, indicated airspeed, aircraft pitch and bank, turn coordinator ball position), and *calculated parameters* (Touchdown vertical velocity, g force).

To simplify the dataset and the analysis of flight smoothness, only aircraft position in space and general acceleration were selected. The acceleration of the airplane is measured with the recorded g force. The ideal acceleration value is 1. Although a perfect acceleration value in practice is not attainable, any major deviation from this ideal value will be caused by the pilot's manoeuvring in case of a disturbance-free flight as was the case in this experiment (no wind, incident or interruptions). Aircraft position in space is recorded as the rotation along its three axes. The three axes in reference to the airplane are commonly referred as the yaw or heading rotation along the vertical axis, the pitch rotation along the lateral axis and the roll rotation along the longitudinal axis (see Fig. 10). Those provide information on how the pilot manoeuvre along those axes to navigate through the required tasks. A smooth flight should have minimal range along all axis and progressive transitions if any since the analysed segments are rectilinear flights with no disturbance.

Figure 10 *- Airplane rotation axes*



Utility perception analysis

Data regarding participants' perceived Utility of the video displayed was self-reported after watching the training video using a questionnaire hosted online by the research team. Participants were asked their agreement on a Likert scale from 1 to 7 with a statement about the perceived utility of the video they just watched (see table 3). Three questions were asked across three dimensions of utility, specifically usefulness, efficiency, and satisfaction. The questionnaire was adapted from a study investigating students' perception of e-learning content (Liaw, 2008).

Table 2 - Utility questionnaire [1]

On a scale from 1 to 7, where 1 means strongly disagree and 7 means strongly agree; please rate the following statements about the training video you just watched.	
Usefulness	1. I believe the training' video's content is informative. 2. I believe the training' video's content is a useful learning tool. 3. I believe the training' video's content is useful.
Efficiency	1. I believe this type of training can assist learning more efficiently. 2. I believe this type of training can assist learning performance. 3. I believe this type of training can assist learning motivation.
Satisfaction	1. I am satisfied with watching this training video as a learning tool. 2. I am satisfied with the training video's content. 3. I am satisfied with the training video's multimedia content.

Note: [1](Abdullah & Ward, 2016; Liaw, 2008)

Analysis

The main goal of the analysis in this study is to detect changes in visual behaviour and operating (i.e. manual flight) performances between groups after the exposition to EMME. We measured participants' performances before and after treatment to validate the initial performances as well as improvements. The comparisons made for the hypothesis were made using the average of a group's measurements. We also measured experts' performance in the same conditions to provide the basis for comparison. All the hypotheses have been verified for every relevant flight phase (takeoff, navigation, landing), resulting in 3 different results per hypothesis per measurement.

All statistical calculations were made using SAS. All reported comparisons were made using the Wilcoxon sum rank test with one or two tails depending on the hypothesis. Reported results respect an experimental threshold of 5%.

To provide a basis for visual behaviour comparison, a golden standard was produced using the experts' performances. An average value of GTE for every flight segment was calculated for both experts. The agreement of both experts was then verified before generating a golden standard. The two experts performed similarly, measured using Cronbach's coefficient ($\alpha = 0.97$). We then averaged the results of experts to have a single reference value for every phase, the golden standard.

In a similar way, the proportional fixation time per AOI was analysed using a golden standard for every AOI in every segment. The measurement for experts was performed the same way as for participants. The value represents the percentage of fixation time a participant or expert gazed inside an AOI. Non-fixation times are excluded from this metric. The agreement of both experts was then verified before generating a golden standard. The two experts performed similarly, measured using Cronbach's coefficient ($\alpha = 0.83$). We then averaged the results of experts to have a single reference value for every phase and AOI.

The manual flight performance of experts was not used in this analysis as an ideal performance value was readily identifiable. All the chosen measurements were compared using the maximum range of both flight tasks in every flight phase. The absolute maximum range was used as all measurements can have negative values. The heading analysis was made using the heading provided by the simulation's objective, e.g., the runway's orientation for takeoff and landing or the indicated heading to follow for navigation.

We performed a baseline verification to ensure there were no differences in visual behaviour or manual flight performance between the groups before treatment. Average measurements for every pre-treatment segment were compared between groups. A second comparison was made the same way to verify that there was a difference post-treatment between groups (H1). Both those comparisons were made using a two-tailed Wilcoxon sum rank test (SAS).

The final performance comparisons for visual behaviour (H1) were made in relation to the golden standard. We calculated the absolute difference between a group's average and the golden standard. We then compared the difference values of both groups to verify the closest to the golden standard.

Comparing manual flight (i.e., operating) performance improvements between flight tasks (H2) was made by calculating each group's difference in performance between flight segments. Smaller values represent a bigger reduction of maximum range thus better improvements between flights.

Self-reported measurements were compared between groups (H3) for each of the three utility qualities investigated (i.e., usefulness, efficiency, satisfaction). An average of the agreement scores with all three items measuring each quality was used for comparison (see Table 2).

2.5 Results

Descriptive statistics

The experiment was conducted with 23 novice pilots completing two flight tasks in a simulator. The groups were randomly assigned to see one of the two versions of the training video between both flights. The experimental group was exposed to a version of the training video containing a representation of the expert gaze while the control group saw the same training video without a gaze representation overlay. Both flight task duration averaged 25 minutes and both versions of the training video averaged 10 minutes. For hypothesis testing, only flight phases of interest (See Fig. 8) were analysed namely the takeoff, rectilinear navigation, and landing with an average duration of 100 seconds, 500 seconds, and 60 seconds respectively.

The gaze data of two participants were lost due to a hardware error. One participant had major difficulties landing the plane and its manual flight performance was removed from analysis due to incomplete data. In total, visual behaviour analysed 21 participants' gaze data and 22 participants' manual flight performance data. Of the remaining participants data, 11 were assigned to the control group for gaze data against 10 for the control group; and 11 were assigned to the control group for manual flight performance data against 10 for the control group.

Three main variables were explored in this study: Visual behaviour as the gaze transition entropy and as the AOI fixation distribution and Operating performances as flight smoothness change. The tables above provide an overview of the results, reported as an average for both groups for each flight phase. The columns showing the golden numbers report on the benchmark performance numbers of the experts' performance. Only the three most common AOI are presented in Table X.

***Figure 11** - Average GTE by phase per group*

	Group	Takeoff			Navigation			Landing		
		Pre	Post	Golden	Pre	Post	Golden	Pre	Post	Golden
GTE	Control	0.0802	0.1281	0.1492	0.1255	0.1067	0.1485	0.0394	0.0526	0.0827
	Treatment	0.0984	0.1216		0.1273	0.1306		0.0538	0.04	

***Figure 12** - AOI fixation distribution by phase per group*

AOI	Group	Takeoff			Navigation			Landing		
		Pre	Post	Golden	Pre	Post	Golden	Pre	Post	Golden
Altimeter	Control	0.093	0.185	0.085	0.185	0.168	0.29	0.023	0.013	0.01
	Treatment	0.12	0.129		0.174	0.204		0.045	0.081	
Anemometer	Control	0.183	0.219	0.385	0.061	0.021	0.075	0.094	0.135	0.225
	Treatment	0.195	0.259		0.062	0.045		0.093	0.102	
Windshield	Control	0.701	0.535	0.46	0.537	0.662	0.415	0.918	0.879	0.765
	Treatment	0.637	0.534		0.536	0.502		0.885	0.897	

Figure 13 - Change in operating performance by phase per group

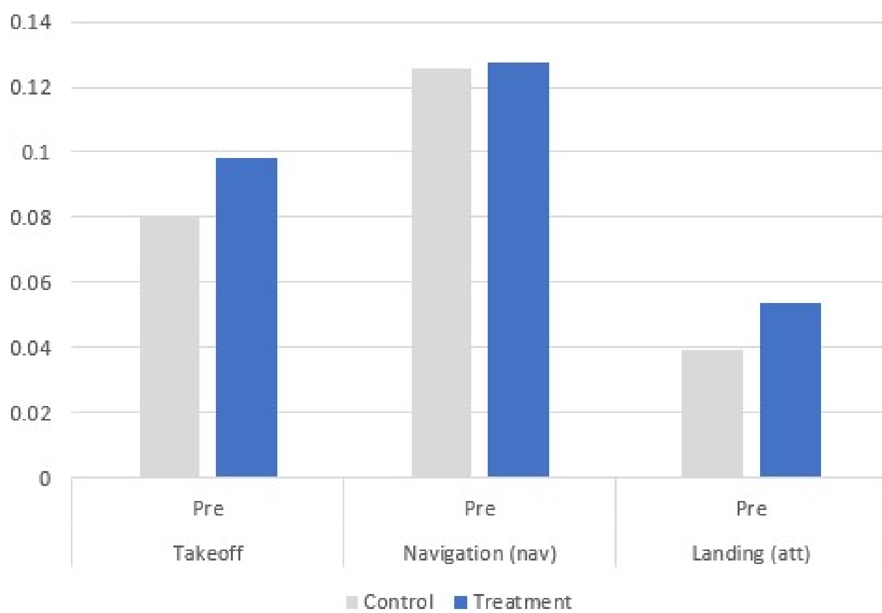
Change in performance		Takeoff				Navigation				Landing			
		Avg	Med	Min	Max	Avg	Med	Min	Max	Avg	Med	Min	Max
gForce	Control	-0.06	-0.11	-0.4	0.5	-0.2	-0.21	-0.38	-0.04	-0.04	0.01	-0.6	0.3
	Treatment	-0.11	-0.05	-0.8	0.1	-0.09	-0.09	-0.37	0.389	0.32	0.01	-0.4	3.8
Heading	Control	-2.98	-0.55	-20.6	11.3	-4.28	-3.22	-14.1	3.342	-20.24	-11.71	-59.5	16.5
	Treatment	-7.55	-4.18	-31.8	2.7	-6.26	-7.46	-12	4.025	13.06	-33.12	-69.9	324.7
Pitch	Control	-1.94	-1.79	-17.1	8.6	-6.59	-5.79	-13.3	-0.78	-2.1	-0.76	-13	3.1
	Treatment	-1.76	-1.35	-11.2	6.2	-6	-5.64	-12.6	-1.11	5.04	-1.38	-5.1	59.5
Bank	Control	-3.42	-1.55	-20	2.7	-2.49	-0.77	-16.9	5.364	-5.62	-0.97	-42	12.1
	Treatment	-7.07	-5.43	-14.7	-2.4	-3.15	-6.24	-11.6	8.089	-2.82	-14.05	-43.6	93.4

Pre-treatment differences between groups

To validate the effectiveness of the random assignment, the pre-treatment performance of both groups was compared to report any differences between groups.

No differences were found between groups prior to treatment in terms of Gaze Transition Entropy, supporting the equality between groups prior to treatment and validating the effectiveness of the random assignment (See Fig. 14).

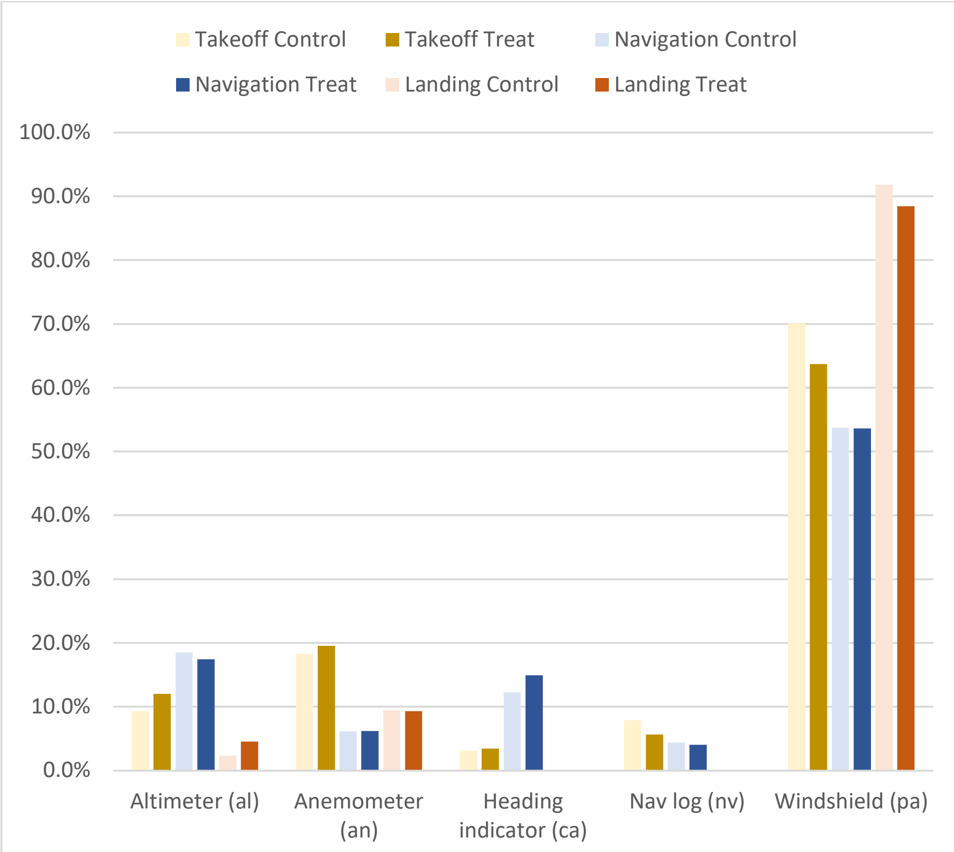
Figure 14 *- Gaze transition entropy before treatment, all flight phases*



Note: No statistically significant differences observed.

Again, no differences were found between groups prior to treatment in terms of proportional fixation time per AOI (%AOI), supporting the equality between groups prior to treatment and validating the effectiveness of the random assignment (See Fig. 15).

Figure 15 - Proportional AOI fixation before treatment, all flight phases



Note: No statistically significant differences are found.
Only AOI with significant (> 5%) fixations in any phase are shown
Compass, turn coordinator ball, side window, NDB and VOR are omitted.

In terms of manual flight performances, random assignment effectiveness was also confirmed. There were no significant differences found between groups, supporting the equality between groups prior to treatment.

Thus, we can confidently report that both groups were equal prior to treatment in all measured aspects and that any differences found afterwards can be attributed to the differences in the training video.

Post-treatment validation

The verification for the impact of the manipulation checks that there is a significant difference between groups post-treatment. This was verified in all flight phases with all measurements.

In terms of gaze transition entropy (GTE), the treatment did not create a significant difference between groups for the takeoff phases. There was a significant difference between groups after treatment in both navigation and landing phases. The GTE of the experimental group in the navigation phase was 0.13062 and the control group was 0.1067 [p = 0.0215], and in the landing phase GTE was measured at 0.4003 in the experimental group and at 0.05264 for the control group [p = 0.0305].

In terms of proportional fixation time per AOI, some significant differences between groups have been found in the navigation and takeoff flight phase, although not every AOI has a significant difference. Results show no difference between groups in the AOI fixations in the takeoff phase after treatment. During the navigation phase, the windshield was fixated 50.1% of the time by the experimental group and 66.2% by the control group [p= 0.00983]; The anemometer was fixated 4.5%% of the time by the experimental group and 2.1% by the control group [p = 0.0079]; The Navlog was fixated 6.9% of the time by the experimental group and 4% by the control group [p = 0.0215]. During the landing phase, the anemometer was fixated 10.2% of the time by the experimental group and 13.5% by the control group [p = 0.01474].

About operating (i.e., manual flight) performance, no statistically significant differences can be observed in terms of manual flight performance after the experimental treatment.

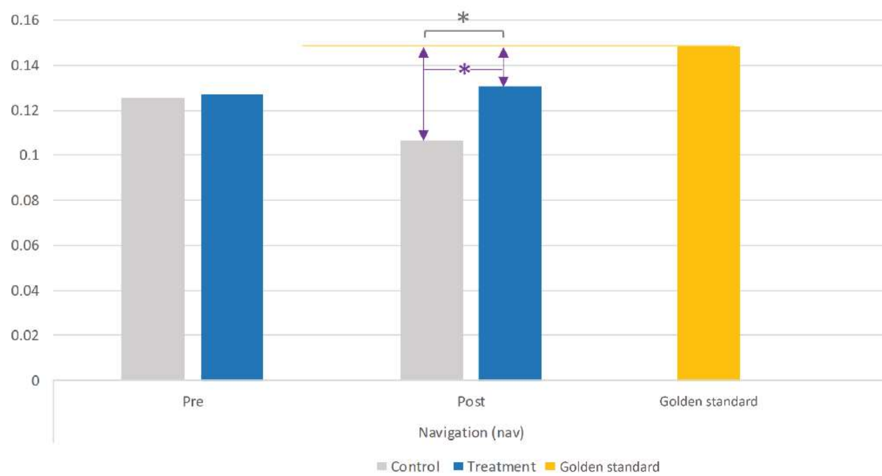
Overall, the results show the impact of the training video in a large portion of flight phases. A clear impact on the visual behaviour of the experimental group was measured in both GTE and proportional fixation time per AOI when compared to the control group. Thus, positively validating the verification of the video's impact on visual behaviour. Manual flight performance according to those results was not significantly affected by the manipulated video or by the observed modification of visual behaviour. Only some impacts have been found as the representation of expert gaze did not have a significant impact on manual flight performance analysed data.

Visual behaviour (H1)

The *imitation of visual behaviour* hypothesis states that the visual behaviour measurement of the experimental group should be significantly closer to the golden standard than the control group. This hypothesis was tested in all flight phases with all visual behaviour measurements. To report closeness to the golden standard, the results report the difference between groups in distance to the golden standard, where a smaller distance can be interpreted as a stronger imitation behaviour and an improvement in visual behaviour performance.

For GTE, the only phase where there was a significant difference in the proximity to the golden standard was in the navigation phase (H1) (See Fig. 16). After treatment, the GTE measured in the navigation segment of the experimental group was significantly closer to the golden standard with a distance from experts of 0.02859 compared to the distance of the control group of 0.04434 [$p = 0.034$].

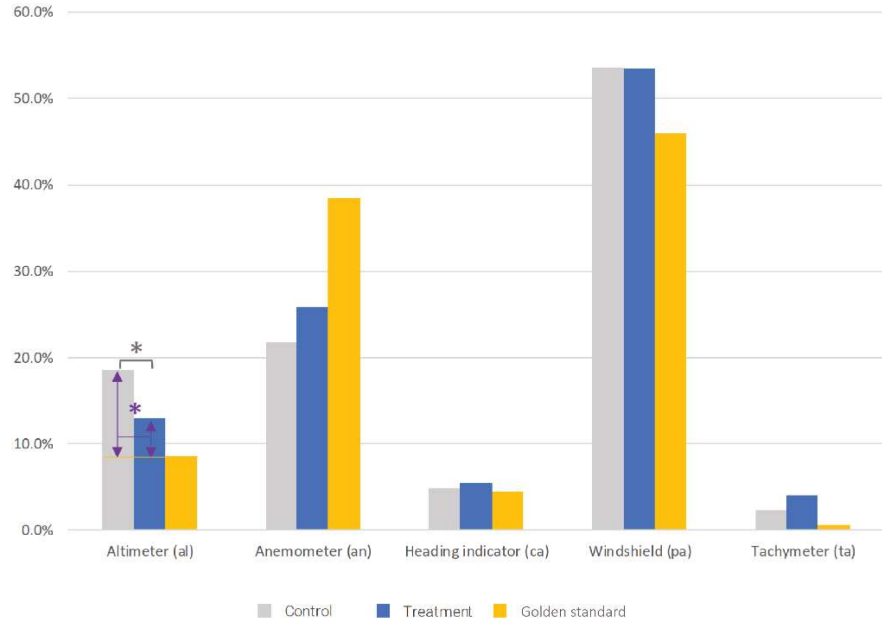
Figure 16 *- Gaze transition entropy compared to golden, Navigation phase.*



Note: * indicates a statistically significant difference ($p < 0.05$)
The purple * indicated the difference of distance from the golden standard (yellow column) between groups.

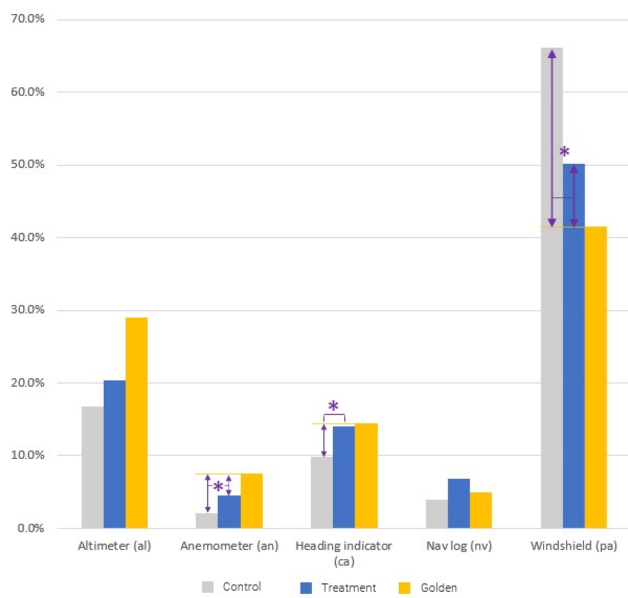
The proximity to the golden standard in terms of proportional fixation time per AOI of the experimental group got bigger in the takeoff and navigation phase for certain AOIs (H1). During the takeoff phase, the altimeter was fixated 12.9% of the time by the experimental group and 18.5% by the control group and the golden standard is 8.5% of the time [$p = 0.00983$] (See Fig. 17). During the navigation phase, the windshield was fixated 50.2% of the time by the experimental group, 66.2% by the control group and the golden standard is 41.5% of the time [$p = 0.00983$]; the heading indicator was fixated 14.1% of the time by the experimental group, 9.9% by the control group and the golden standard is 14.5% of the time [$p = 0.00983$]; and the anemometer was fixated 4.5% of the time by the experimental group, 2.1% by the control group and the golden standard is 7.5% of the time [$p = 0.036$] (See Fig. 18)). There was no significant difference in distance from golden standard in the landing phase.

Figure 17 - Proportional AOI fixation proximity to golden standard after treatment, Takeoff phase



Note: * indicates a statistically significant difference ($p < 0.05$)
The purple * indicated the difference of distance from the golden standard (yellow column) between groups.

Figure 18 - Proportional AOI fixation proximity to golden standard after treatment, Navigation phase



Note: * indicates a statistically significant difference ($p < 0.05$)
The purple * indicated the difference of distance from the golden standard (yellow column) between groups.

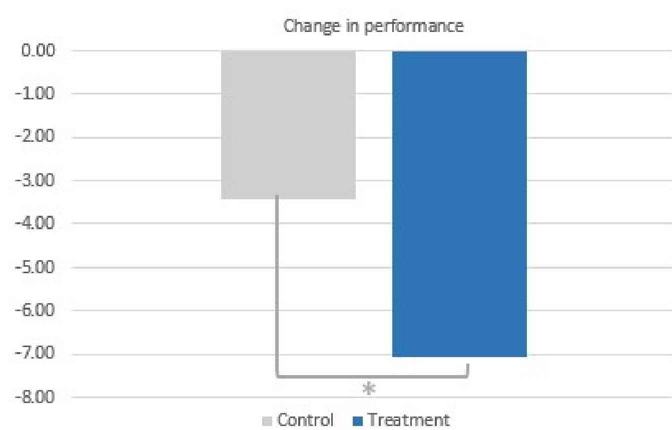
Overall, the results support the hypothesis of the imitation of visual behaviour (H1). The clear modification of many visual behaviour measurements of the experimental group towards the golden standard shows a clear trend of modifying the visual behaviour of novices exposed to an expert's gaze representation through an eye movement modeling example in a training video. Even though some AOI of flight phases did not show significant differences, the lack of improvement of the control group compared to the experimental group let us support the hypothesis that seeing a gaze representation causes an imitation of presented visual behaviour.

Operating (i.e., manual flight) Performance (H2)

The second hypothesis proposes that the operating (i.e., manual flight) performance of a group of novices exposed to a representation of an expert's gaze through an eye movement modeling example training video would be improved when compared to a conventional training video. This hypothesis was tested for all four measurements in all flight phases of interest. The results report the diminution in the maximum range of flight controls measured in each phase (See Fig. 19).

Only one measurement of manual flight performance via flight smoothness during the takeoff phase resulted in a significant improvement of performance when compared to the ideal performance value. The experimental group had a bigger reduction of maximum bank range with a 7.07 degree of bank range reduction compared to the control group's reduction of 3.42 degrees of bank range [$p = 0.009$].

Figure 19 *- Flight performance - Takeoff bank range improvement*



Note: Lower numbers indicates bigger improvements.
Negative numbers mean reduction of maximum range.

The results do not support the hypothesis that manual flight performances would be improved by the exposition to an expert's gaze representation through an eye movement modeling example training video. The discussion section discusses the possible factors influencing the lacking results of this analysis.

Perceived value of training video (H3)

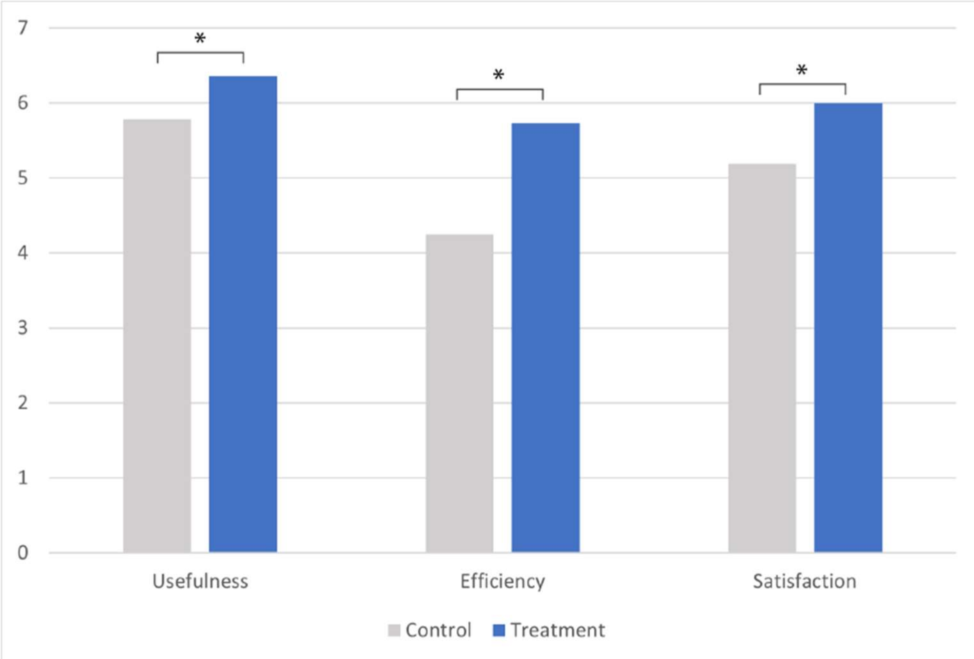
We hypothesised that the reported perceived utility of a training video would be higher when surveying a group of novice pilots exposed to a version of a training video featuring a representation of an expert gaze through an eye movement modeling example. This measurement was self-reported with an agreement score with a statement on a Likert scale from 1 to 7, after watching the assigned version of the training video (See Table 3).

Table 3 - *Self-reported utility measurements*

Self reported perceived utility					
Condition	**N Obs.**	**Variable**	**Mean**	**Median**	**Std Dev**
Control	12	Usefulness	5.78	5.83	0.72
		Efficiency	4.25	4.00	1.22
		Satisfaction	5.19	4.83	0.86
Experimental	11	Usefulness	6.36	6.33	0.46
		Efficiency	5.73	5.67	0.90
		Satisfaction	6.00	6.00	0.58

Self reported perceived utility of video has shown a significant difference in all aspects measured and supports the corresponding hypothesis (H3). Experimental group shows a significantly higher perceived usefulness with a mean of 6.36 compared to 5.19 [$p = 0.0485$], a higher perceived efficiency with a mean of 5.73 compared to 4.25 [$p = 0.0071$] and a higher perceived satisfaction with a mean of 6.36 compared to 5.78 [$p = 0.0164$] than the control group. (See Fig. 20)

__Figure 20__ - Self-reported utility comparison



Note: * indicates a statistically significant difference ($p < 0.05$)

The results support the hypothesis that adding a representation of an expert gaze in a training video through an eye movement modeling example would increase the perceived value of the training content. In fact, all measured utility aspects were found to be significantly higher by the experimental groups. Implications of this hypothesis on the motivation of participants is discussed in the next section.

2.6 Discussion

This study indicates that overlaying an expert's gaze on a training video has positive impacts on the student pilots' visual behaviour, flight performance and perceived utility of the training content. Findings are aligned with the existing literature concerning this training method and provide great opportunities to guide the production of this type of training content. While there is a difference in the degree of effect of the training depending on the flight regime, adding a visual marker to the training video always increased the perceived value of the training content.

Beginning with the most straightforward results, are the differences in the self-perceived utility of the training video. The experimental group found the video to be more useful, efficient, and satisfactory in their training. Literature on the subject has those self-perceived utility qualities linked to learning motivation and performance (Fussell & Truong, 2020; Liaw, 2008). The higher perceived utility of the video is a great indicator of its potential value both for pedagogical and commercial considerations. Regardless of the impacts on actual behaviour, the increased perceived value of the exposition to experts' gaze shows great promise in its goal to enhance training material and methods for student pilots.

In turn, the findings regarding visual behaviour and flight performance results are slightly less unequivocal, but they do lead to the conclusion that exposition to an expert's gaze has a significantly positive impact on visual behaviour. When presenting results by phase, the analysis shows a clear benefit to visual and flight performance in the navigation phase, a tendency to have a positive impact on takeoff visual behaviour and mixed results in the landing phase.

By phase

During the **takeoff** phase, few changes to performance were caused by the manipulated video. The only difference caused by the manipulation is an improvement in the manual fight performance. A reduced maximum range of bank during takeoff is arguably the most important axis to control during this phase. That improvement might be the result of the non-statistically significant changes in the AOI fixations that were measured, although neither the crude statistical analysis nor a more intuitive analysis of the changes provides an adequate explanation to the changes. It was hypothesized that observing a behaviour would help novices learn the behaviour, in accordance with the social learning theory. The lack of difference between groups after the manipulation might be explained by the simplicity of the observed visual behaviour during takeoff. In fact, the training video script advises to keep looking at the runway with short looks towards speed and tachymeter. Although the selected gaze representation sequence shows this pattern clearly, visualising such a simple sequence might not necessitate the help of a signaling addition.

For the **navigation** phase, the results show a clear improvement and a stronger imitation of expert behaviour by the experimental group. The change directions in the groups' performances were opposite, with the experimental getting significantly closer to the golden standard. In addition, we can see a proportion of fixation towards three main AOIs for the navigation phase being significantly closer to the golden standard for the experimental group. Two factors might influence the clearer results for this phase. First, this segment is significantly longer, with an average time of 500 seconds against 60 and 105 for the takeoff and landing phases respectively. The resulting data results in a bigger capacity to detect changes caused by the experimental manipulation. Those results in a longer and more nuanced phase of the flight points to the fact that a more complex scanning pattern might be communicated more effectively with gaze representation than with simple speech. Those results do not translate to an increase in manual flight performance, which might be the result of the simplicity of the flight manoeuvre. A straight and level flight might be as smooth with inappropriate scanning patterns causing the pilots to not generate an appropriate awareness of the flight's status. This lack of awareness might be better measured in the advent of an emergency or a progressive defect.

The **landing** phase produced mixed results. In fact, the GTE of the experimental group increased less than the control group, trending in the opposite direction of the expert's GTE. This seemingly worse performance could be explained by the additional fatigue that might have been induced by the training video representation of the expert's gaze. Contrary to what we expected from the guidance of CTML, the additional information might have demanded additional cognitive resources during the viewing and for the following flight via a heightened awareness of their own visual behaviour. In terms of AOI fixation, the experimental group had a small shift in attention from the anemometer to the windshield between the two flights which produced a smaller deviance from experts for the windshield and a bigger deviance for the anemometer. It needs to be pointed out that the script told participants that the windshield was the most important AOI followed by the anemometer.

Regarding the conceptual frameworks of social learning theory and cognitive theory of multimedia learning, we can now interpret the findings with the participant's cognitive activity in mind. The results show that observing the visual behaviour of experts did lead to an imitation behaviour and consequently to improved scanning behaviours. In fact, most differences between groups were found in the visual behaviour of participants thereby suggesting the importance of the observation of a model's behaviour in the manipulated video's impact. While some phases of the flight are not significantly impacted, the simplicity of the behaviour shown might not have been beneficial for novice pilots with some existing flight experience. On the other hand, CTML tells us that better design of educational content manages learners' cognitive processes efficiently and therefore leads to better learning. We thus expected participants exposed to the expert gaze to have stronger benefits in learning measured as improved performances. While the cognitive activity of participants was not measured, the significant improvement in visual performance of the experimental group suggests the validity of the identified theoretical frame used in the operationalisation of the experts' gaze as an attentional guide. We consider the results as contributing to the argument that signaling visual content with an expert's gaze is beneficial in the context of training novice pilots.

The close relationship between perceived ease of use, motivation and learning may also be a contributor to the observed increase in performance. A higher perception of usefulness, efficiency and satisfaction reported by the experimental group could be associated with better learning performances and incidentally with higher motivation.

2.7 Conclusion

This study investigated the efficiency of training novice pilots to better visual scanning strategies via exposition to an expert's gaze representation (EMME). The results show that a video enhanced with a representation of an expert's gaze has the potential to positively impact novice pilots' visual behaviour, flight performance and perceived utility of the training content. Higher perceived utility has been linked to enhanced learning performance in e-learning literature (Abdullah & Ward, 2016). Depending on the flight regime, data from this study suggest that the impact on flight performance and visual behaviour varies, being most beneficial for the takeoff phase, somewhat beneficial for navigation and mixed for the landing phase.

Limitations and future work

While the findings of this study do provide sufficient evidence to say there is value in the proposed training method, the scope of the study remains exploratory, and the generalisation of those findings is limited. Two main limits can be identified: the nature of the improvements measured and the sample size.

Firstly, the experiment measured the improvement of novice pilots right after watching a 10-minute training video. The exact nature of those improvements was out of the scope of the study, and therefore it can only report on the sporadic behaviour improvements. Some theories could be evoked to point out the limited impact of sporadic behaviour change in the overall skill-learning process. As a matter of fact, a major component of skill training is the long-term integration of desired behaviour by the trainee. While the practice of those behaviours is a main contributor to the long-term integration, a longitudinal measurement of improvements would provide a clearer answer as to the value of the exposition to an expert's gaze during the training. A longitudinal experiment similar to the one proposed, following a cohort of pilots through their flight training would shine a light on the different effects on learning caused by the exposition to the expert's gaze.

A second limiting factor of the study is its sample size. The context of the study greatly limits the pool of potential participants as it demands a specific point in skill proficiency where scanning patterns are not limited by instrument reading but where a training video on said strategies can provide a significant improvement in scanning strategies. The current sample size of 23 limits the power of the statistical analysis. Although, the participants were recruited in a highly selective piloting school (~10% acceptance rate), which in turn provided a rather homogenous sample. A different experiment design where participant proficiency has an extended range could provide another experiment with a much larger sample size, a much bigger statistical strength, and more general insights on expert gaze exposition training.

Implications for future research

The scope of this study was exploratory, and the findings do provide serious arguments to pursue research about exposition to expert's gaze. Implications in the actual field of pilot training as well as the possible future research are multiple.

The overarching aim of this study was to evaluate the value of a novel training method for a known air travel safety issue in the context of training novices. The findings of this study seem to provide a plausible means to reduce the prevalence of improper cockpit monitoring in future pilots: novice training for better visual scanning strategies. The actual impact on long-term skill learning needs to be studied further, but the enhanced perceived value of this content would most certainly raise awareness and motivation of novice pilots towards visual strategies.

Eye-tracking research has been around for a long time, and the adoption of this technology in newer fields is expected to create significant growth opportunities in the coming years (Carter & Luke, 2020). The present study investigated one possible use of the technology as a value-creation tool rather than as an evaluation tool. Without a doubt, including expert gaze representation seems to be a valuable way to produce training content, especially when access to this technology is growing. The current study aimed and succeeded at advocating the value of producing such content by major pilot training actors. Although a gaze representation enhanced video seems valuable, further research is necessary to create guidelines, actionable recommendations and to deepen our understanding of gaze-representation training.

From a research standpoint, various directions open themselves to further investigation in the same context. To further understand the impact of this training in general, future research having a "without video" control group would help to evaluate the impact of the whole training content rather than simply the video manipulation.

In sum, our findings strongly suggest that the exposition to the representation of the expert's gaze via video is an efficient training activity that should be further investigated. Future research should investigate different methods of integrating and representing an expert's gaze as well as the long-term inclusion of such training material in a novice pilot's training.

2.8 Appendix

Appendix 1

Training video narration Script (English version)

Introduction

This short training capsule aims to make you aware of the behaviour of your gaze in flight, specifically for the exercise you are going to do next. The exercise is the reverse route of the first three exercises but without the help of the virtual instructor. You will still have objective indicators. The video shown in the background is taken from recording excerpts of the same exercise performed by an expert pilot. Although in-flight instrument monitoring strategies are primarily taught for instrument flight, a pilot's visual behaviour is a crucial aspect of maintaining safe visual flight as well. The main difference is that the exterior of the aircraft in visual flight provides much more information than the instruments and therefore occupies a significant portion of the visual attention. The next sections will tell you about visual scanning strategies in four different flight regimes:
level flight, take-off, turns, and landing.

Level flight

We will begin the introduction of good in-flight visual scanning strategies by starting with the simplest regime: level flight. This is the most monotonous flight regime, and the pilot therefore becomes susceptible to distractions and loss of attention. It is therefore a phase where the practice of a good systematic scan is important. Good visual scanning is manifested by the appearance of two features in a pilot's visual path: Prioritization of instruments and recurring patterns.

Prioritization of instruments in the visual path begins with a good knowledge of flight systems. Fortunately, plane's dashboards instrument layouts are designed taking this prioritization into account.

In general, the more critical the instruments are to the flight, the closer they are to center. In visual flight, prioritization begins with looking outside. Indeed, the majority of flight parameters can be monitored with a look outside. The instruments are used to verify the information that the pilot gathers from the outside. The pilot will then have to prioritize the instruments according to the flight regime. In cruise flight, the altimeter and the heading indicator are essential, followed by the airspeed indicator and the tachometer.

Recurring patterns in visual scanning comes naturally once prioritization is well integrated. In fact, these patterns emerge when errors are less frequent. Three types of errors in the visual scanning behaviours of airplane pilots can be identified: Fixation, emphasis, and omission.

Fixation occurs when a pilot focuses all their attention on one instrument. The pilot physically stares on one instrument and never looks at any other instrument. He then loses awareness of other flight parameters and can slowly switch to a dangerous flight regime without realizing it.

Emphasis is a more subtle error that occurs when a pilot gives too much of their attention to a single instrument to track a flight parameter. For example, a pilot who only looks at his altimeter to maintain his altitude does not use all the information available to maintain altitude. He should look at other instruments to confirm the information, in this example the variometer.

The last type of error is omission, which occurs when a pilot fails to look at an instrument. If a pilot never looks at a backup or standby instrument, they won't notice if it begins to fail. If ever this secondary instrument becomes necessary due to a failure in the main instruments, the pilot will not be able to refer to it, creating a safety hazard.

Therefore, always keeping a greater part of his attention outside, the pilot must scan his instruments to avoid fixations, omissions and placing too much emphasis on a single instrument.

Takeoff

Upon applying the power required for takeoff, the pilot should look at his engine instruments to reconfirm that all systems are working properly. Once full power is applied, the pilot should turn all its attention outside the aircraft since it is the visual area that gives the most information about the aircraft’s behaviour. The runway line is a good reference point during the take-off roll to ensure that you keep a good trajectory. It also gives a good speed reference. To complete a successful takeoff, you still need to take a quick look at the airspeed indicator to make sure you have enough speed to lift off. Additionally, reconfirming that the tachometer is behaving normally is good practice to detect any engine abnormalities.

Once the aircraft is airborne, care must be taken to maintain an adequate climb speed and attitude using those same instruments. The visual scan should alternate between the exterior of the aircraft and the airspeed indicator with a few brief glances at the engine instruments. In this critical flight phase, the pilot should not look at information concerning the route, it is important to make sure to have read this information before departure so as to not have to dedicate part of our attention in this critical moment. Once the speed is stabilized, the altimetric instruments can be integrated into this cycle, i.e., the altimeter and the variometer, to ensure a controlled, safe, and efficient climb. Always keep in mind, the windshield is the instrument that will give you the most information on the behaviour of your aircraft.

Turns

Just like for takeoff, the pilot must take care to look at the information on the route before initiating the maneuver. It is important to know the course to be reached with the turn before initiating it. When entering the turn, it is again the outside of the aircraft that will give most of the information: you can see the rate of inclination, the coordination of the turn, the altitude, and the direction. Once the maneuver is visually stable, the pilot must, as in cruise flight, confirm the information he sees using his instruments. The heading indicator gains priority since it becomes critical in knowing when to exit the turn. It may be more difficult to maintain altitude while maneuvering and harder to notice. We should therefore see the pilot's attention more frequently scan the exterior, the heading indicator, and the altitude in a turn. Once again, it is important to check secondary instruments in this maneuver to ensure that the flight and the aircraft remain in control. We therefore complete the scan with brief glances at the tachometer, the airspeed indicator, and the turn coordinator.

Arrival & landing

In the arrival phase preceding the landing, it is important to know your arrival procedures and as mentioned earlier, to know your flight information before initiating a maneuver. Fortunately, the simulator gives you visual indicators of the path to follow. We can therefore see, for example, a visual cue of the point where we should turn on final, which reduces the importance of finding your way around the circuit. The base segment of the circuit is where attention management becomes crucial. The instruments that should be prioritized are the Exterior of the aircraft, the airspeed indicator, and the altimeter. Despite the visual cues given by the simulator, it is important to remain aware of the location and behaviour of the aircraft in space. The airspeed indicator is important to ensure that you reach the correct approach speed without approaching a stall. The altimeter ensures that the descent is not too steep and that the flight remains safe. Validating the altimeter information with the vertical speed indicator is good practice when turns and speed are under control and the heading indicator can be used as a reference to ensure you have a good trajectory.

Once the final turn has been made, the pilot's gaze should only leave the runway to quickly ensure that the speed is not too low. The approach slope indicator or Papi lights which are located to the left of the runway is also a good tool instrument which does not divert the pilot's attention. As a reminder, four white lights mean the approach slope is too high while four red lights mean it is dangerously low. Two reds and two whites mean a good approach slope. Again, the pilot should look primarily at the runway until touchdown. In short, a good visual scan in visual flight is based on a good prioritization of the instruments observed thanks to the understanding of the most important parameters for each flight regime.

Thank you for your attention and happy flying!

Appendix 2
Training video narration script (French version)

Introduction

Cette courte capsule de formation souhaite vous sensibiliser au comportement de votre regard en vol, spécifiquement pour l'exercice que vous allez faire par la suite. Il s'agit du trajet inverse des trois premiers exercices, mais sans l'aide de l'instructeur virtuel. Vous aurez tout de même des indicateurs d'objectifs. La vidéo présentée à l'arrière est tirée d'extraits d'enregistrement de l'exercice performé par un pilote expert. Bien que les stratégies de monitoring d'instrument en vol soient principalement enseignées en vue de faire du vol aux instruments, le comportement visuel des pilotes est également un aspect important pour le maintien d'un vol à vue sécuritaire. La principale différence étant que l'extérieur de l'avion en vol à vue fournit beaucoup plus d'information que les instruments et vient donc occuper une partie importante du balayage visuel. Les prochaines sections vous parleront des stratégies de balayage visuel dans quatre différents régimes de vol soit : le vol en croisière, le décollage, les virages et l'atterrissage.

Vol en croisière

Nous allons commencer l'introduction de bonnes stratégies de balayage visuel en vol en commençant par le régime le plus simple : le vol en croisière. Il s'agit du régime de vol le plus monotone et le pilote y devient par conséquent susceptible aux distractions et à la perte d'attention. C'est donc une phase où la pratique d'un bon balayage systématique est importante. Un bon balayage visuel se manifeste par l'apparition de deux caractéristiques dans le parcours visuel d'un pilote : une priorisation des instruments et des motifs récurrents.

La priorisation des instruments dans le parcours visuel commence par la connaissance des systèmes de vol. Heureusement, les tableaux de bord sont conçus en prenant compte de cette priorisation dans la disposition des instruments. En général, plus les instruments sont cruciaux au vol, plus près ils sont du centre. Dans le vol à vue, la priorisation commence par le regard à l'extérieur. En effet, la majorité des paramètres de vol peuvent être monitorés avec un regard à l'extérieur. Les instruments servent à vérifier l'information que le pilote dérive de l'extérieur. Le pilote devra par la suite prioriser les instruments selon le régime de vol. En vol de croisière, l'altimètre et l'indicateur de cap sont primordiaux, suivis de l'anémomètre et du tachymètre.

Les motifs récurrents dans le balayage visuel arrivent naturellement une fois que la priorisation est bien intégrée. En fait, ces motifs émergent lorsque les erreurs sont moins fréquentes. On identifie trois types d'erreurs dans les comportements de balayage visuel chez les pilotes d'avion :

La fixation, l'emphase et l'omission.

La fixation survient lorsque le pilote donne toute son attention à un seul instrument. Il perd alors l'information du reste des paramètres du son vol et peut tranquillement passer vers un régime de vol dangereux sans s'en rendre compte.

L'emphase est une erreur plus sournoise qui survient lorsqu'un pilote accorde une trop grande partie de son attention à un seul instrument pour suivre un paramètre de vol. Par exemple, un pilote qui regarde uniquement son altimètre pour maintenir son altitude n'utilise pas toute l'information disponible pour avoir un bon maintien d'altitude. Il devrait regarder d'autres instruments pour confirmer l'information, notamment le variomètre.

La dernière erreur est l'omission. Certains instruments moins importants sont négligés par les pilotes. Si un pilote ne regarde jamais un instrument alternatif ou secondaire, il ne remarquera pas s'il cesse de fonctionner, ce qui ajoute un risque inutile. Si jamais cet instrument secondaire devient nécessaire à cause d'un bris dans les instruments principaux, le pilote ne pourra pas s'y référer.

En gardant toujours une partie de son attention à l'extérieur, le pilote doit donc s'efforcer de bien balayer ses instruments du regarde pour éviter les fixations, les omissions et de mettre une trop grande emphase sur un seul instrument.

Décollage

En appliquant la puissance nécessaire au décollage, le pilote devrait regarder ses instruments moteurs pour reconfirmer que la mécanique fonctionne. Une fois que la pleine puissance est appliquée, l'attention du pilote devrait se tourner vers l'extérieur de l'avion puisque c'est la zone qui donne le plus d'information sur le comportement de l'aéronef. La ligne de piste est un bon repère lors de la course au décollage pour s'assurer de garder une bonne trajectoire et donne également un repère de vitesse. Pour compléter un décollage bien réussi, on doit tout de même jeter de bref coup d'œil à l'anémomètre pour s'assurer d'avoir une vitesse suffisante pour décoller. De plus, reconfirmer que le tachymètre se comporte normalement est une bonne pratique pour détecter toute anomalie moteur. Une fois que l'avion est en vol, il faut s'assurer de maintenir une vitesse de montée ainsi qu'une assiette adéquate à l'aide des mêmes instruments. Le balayage visuel devrait alterner entre l'extérieur de l'avion et l'anémomètre avec quelques brefs regards vers les instruments moteurs. Dans ce moment critique du vol, le pilote ne devrait pas regarder d'information concernant le trajet, il faut s'assurer de bien avoir pris connaissance de ces informations avant le départ pour ne pas avoir à y dédier une partie de notre attention dans des moments critiques. Lorsque la vitesse est bien stabilisée, on peut intégrer les instruments altimétriques à ce cycle, soit l'altimètre et le variomètre, pour s'assurer d'avoir une montée contrôlée, sécuritaire et performante. Toujours garder en tête, le parebrise l'instrument qui vous donnera le plus d'information sur le comportement de votre avion.

Virage

Tout comme pour le décollage, le pilote doit prendre soin de regarder l'information sur le trajet avant d'amorcer la manœuvre. Il est important de bien connaître le cap à atteindre avec le virage avant de l'amorcer. En rentrant dans le virage, c'est l'extérieur de l'avion qui donnera la majorité de l'information : on peut y voir le taux d'inclinaison, la coordination des palonniers, le maintien de l'altitude et la direction. Une fois que la manœuvre est visuellement stable, le pilote doit tout comme en vol en croisière confirmer les informations qu'il voit à l'aide de ses instruments. L'indicateur de cap gagne en priorité puisqu'il devient critique à connaître le moment de sortie du virage. Il peut être plus difficile de maintenir son altitude en manœuvre et également plus difficile de s'en rendre compte. On devrait donc voir l'attention du pilote balayer plus fréquemment l'extérieur, l'indicateur de cap et l'altitude. Encore une fois, il est important de jeter des coups d'œil aux instruments secondaires dans cette manœuvre pour s'assurer que le vol et l'avion restent en contrôle. On complète donc le balayage avec de bref coup d'œil au tachymètre, à l'anémomètre et au coordonnateur de virage,

Arrivée et atterrissage.

Dans la phase d'arrivée qui précède l'Atterrissage, il est important de bien connaître ses procédures d'arrivée et comme mentionné plus tôt, de bien connaître les informations de son vol avant d'amorcer une manœuvre. Heureusement, le simulateur vous donne des indicateurs visuels du chemin à suivre. On peut donc voir par exemple un repère visuel du point où l'on devrait virer en finale, ce qui diminue l'importance de bien se repérer dans le circuit. Le segment de la base du circuit est le moment où la gestion de l'attention devient cruciale. Les instruments qui devraient être priorisés sont l'Extérieur de l'avion l'anémomètre et l'altimètre. Malgré les repères visuels donnés par le simulateur, il est important de garder conscience de l'emplacement et du comportement de l'aéronef dans l'espace. L'anémomètre est important pour s'assurer d'atteindre la bonne vitesse d'approche sans se rapprocher du décrochage. L'altimètre permet de s'assurer que la descente n'est pas trop prononcée et que le vol reste sécuritaire. Valider l'information de l'altimètre avec le variomètre est une bonne pratique lorsque les virages et la vitesse sont sous contrôle et l'indicateur de cap peut servir de référence pour s'assurer d'avoir une bonne trajectoire. Une fois le virage en finale effectué, le regard ne devrait quitter la piste que pour rapidement s'assurer que la vitesse n'est pas trop basse. L'indicateur de pente d'approche ou Papi light qui se situe à gauche de la piste est également un bon outil qui ne dévie pas l'attention du pilote et communique de l'information sur le vol. À titre de rappel, quatre lumières blanches signifient que la pente d'approche est trop haute alors que quatre lumières rouges signifient qu'elle est dangereusement basse. Deux rouges et deux blanches signifient une bonne pente d'approche. Encore une fois, le pilote devrait regarder principalement la piste jusqu'au poser de roues.

En somme, un bon balayage visuel en vol à vue se base sur une bonne priorisation des instruments regardés grâce à la compréhension des paramètres les plus importants pour chaque régime de vol.

Merci de votre attention et bon vol!

Appendix 3

Additional screen capture of the training video

Figure 20 - Training video introduction screen

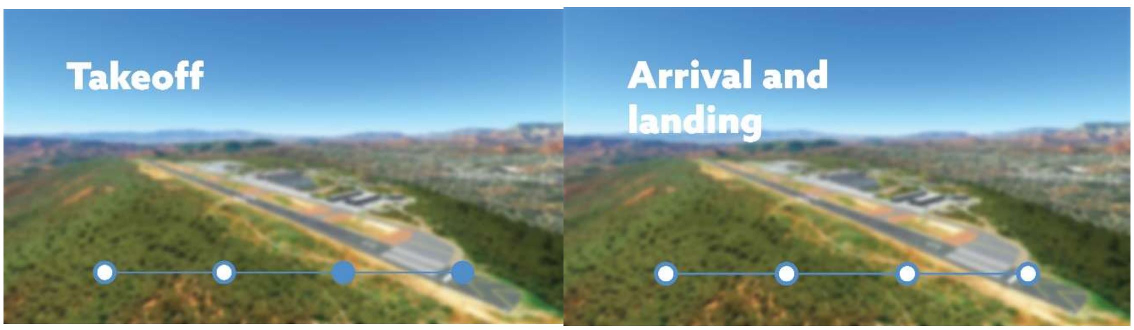


Figure 21 - Transition screens
(Left: Before takeoff phase; Right: before arrival and landing)

Figure 22 - Additional training video screenshots

(Top left: Before Landing; Top center: takeoff; Top right: Landing
Bottom left: Turn; Bottom center: arrival; Bottom right: Level flight)

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Chapitre 3
Entraîner le regard de pilotes à l'aide de celui d'experts

Utiliser l'enregistrement du regard d'un expert comme guide visuel pour entraîner des pilotes novices à adopter de bonnes pratiques visuelles s'avère être un outil efficace. Exposer des novices à ce type de formation permet de générer un comportement visuel s'approchant des experts après un seul visionnement.

Introduction

Le transport aérien d'aujourd'hui est l'un des moyens de transport des plus sécuritaire. Ce haut niveau de sécurité est dû en partie à la grande quantité de recherche scientifique qui se sont intéressées aux avions et aux pilotes, mais également aux enquêtes sérieuses qui sont conduites à la suite d'accidents. En effet, les organisations internationales régissant le transport aérien émettent des normes sur les procédures d'enquête d'accidents aéronautiques qui mènent à la production de rapports exhaustifs par les entités responsables.

Depuis environ deux décennies, les enquêtes ont identifié un facteur récurrent causant les accidents : le balayage visuel inadéquat du poste de pilotage par les pilotes experts. Un balayage visuel du cockpit efficace est une compétence cruciale pour que les pilotes puissent maintenir un vol sécuritaire. Ce balayage permet aux pilotes de maintenir une conscience de leur environnement, connu sous le nom anglais de *Situation Awareness*. C'est la mise à jour constante de cette conscience environnementale qui permet aux pilotes de suivre le positionnement de l'aéronef, d'anticiper les changements et de prendre des décisions éclairées.

Étudier les comportements visuels a fait l'objet de recherches qui depuis longtemps tentent d'établir les relations entre nos yeux et notre cognition. C'est entre autres à l'aide de capteurs oculométriques, qui enregistrent la position du regard d'un participant, que nous pouvons y arriver. Le développement de ces capteurs permet aujourd'hui d'avoir des instruments précis, accessibles et peu intrusifs pour conduire des recherches sur les comportements visuels. Il s'agit d'une technologie transformatrice pour l'étude sur le balayage visuel des pilotes et par le fait même pour l'entraînement de cette compétence. L'enregistrement du regard permet de quantifier les comportements visuels, par exemple en établissant un indice du caractère aléatoire du regard ou bien en définissant la distribution du regard parmi plusieurs zones d'intérêt.

Une méthode d'entraînement des comportements visuels novatrice, qui a émergé du champ de recherche sur les comportements oculaires, est la représentation du regard d'expert comme guide attentionnel. Cette méthode, plus communément appelée Eye Movement Modeling Example (EMME) en anglais, consiste à utiliser l'enregistrement oculométrique d'un expert performant une tâche pour montrer à un novice comment devrait se comporter son regard. L'observation du comportement visuel qui précédemment n'était que schématisé permet aux élèves d'imiter ces comportements, de mieux les intégrer à leurs connaissances antérieures et donc à mieux apprendre. Alors que l'EMME a été étudié dans divers contextes, son utilisation n'a jamais été étudié comme une méthode pour améliorer les vidéos d'entraînement pour pilotes.

Une expérience concluante

Une expérience a été conduite auprès de 23 pilotes novices a été conduite pour valider l'approche utilisant le regard d'expert comme guide attentionnel. L'enregistrement du regard d'expert lors d'un vol simulé a été utilisé comme guide attentionnel dans une vidéo de formation. Cette vidéo de formation a ensuite été présentée à la moitié des participants puis des données mesurant leur amélioration en termes de comportement visuel, performance manuelle en vol et valeur de la vidéo perçue ont été collectées. Les résultats de cette expérience montrent un rapprochement entre le comportement visuel des novices exposé à la vidéo représentant le regard des experts et le comportement visuel de ces derniers.

Les résultats démontrent que lors de la phase de navigation rectiligne, les comportements oculaires des participants se sont significativement rapprochés des experts en termes de complexité. Autrement dit, ils ont amélioré leur stratégie de balayage du poste de pilotage. La phase de navigation dans un vol est longue et monotone et le regard d'un pilote doit demeurer actif pour détecter tout changement inattendu. La représentation visuelle du regard d'expert a permis aux novices d'intégrer ce concept plus rapidement à leurs comportements que le groupe contrôle. La courte durée des phases de décollage et d'atterrissage en plus de leur complexité réduite n'a pas permis de détecter de changement significatif. Puisque les vols simulés se sont déroulés dans des conditions parfaites, les mouvements du regard dans ces phases restent très simples et tous les pilotes peuvent facilement visualiser ce type de comportements sans guide visuel.

On voit une nette amélioration pour le groupe exposé au regard de l'expert. On observe ces changements dans la phase de l'atterrissage en plus de la phase de navigation. On remarque que la proportion de l'attention dirigée change globalement pour se rapprocher du comportement des experts. Ce changement global démontre une compréhension de l'attention attribuée de façon démesurée à un instrument. Le groupe contrôle affiche moins de changement que le groupe expérimental ce qui nous indique que d'apercevoir le regard d'un expert encore une fois permet aux novices d'intégrer des comportements plus rapidement à leur pratique.

La valeur du vidéo de formation rapportée par les participants a été significativement plus haute chez ceux exposés au regard de l'expert. Ils ont effectivement trouvé la vidéo d'entraînement plus utile, efficace et satisfaisante. La littérature scientifique a établi des liens entre la perception de valeur et la motivation dans le contexte d'apprentissage autorégulé. La motivation est également reliée au taux de succès des programmes d'entraînement de pilotes. On peut donc voir un lien possible entre l'ajout de la représentation du regard d'un expert simplement par la motivation accrue qu'il entraîne.

Conclusion

Bien que davantage de recherche soit nécessaire pour déterminer la meilleure façon de concevoir du matériel de formation incluant une représentation vidéo du regard d'un expert, la présente étude démontre clairement un potentiel de valeur ajoutée de cette nouvelle technique de formation. Les pilotes novices exposés à une telle vidéo y perçoivent une valeur clairement supérieure au niveau de l'utilité, de l'efficacité et de la satisfaction. De plus, l'échantillon a tout de même permis de trouver un rapprochement des comportements visuels de novices à ceux des experts. La performance de cette approche d'entraînement représente une direction intéressante pour remédier aux compétences de balayage visuel inadéquat des pilotes.

Chapitre 4
Conclusion

Rappel des objectifs et résultats

L'objectif de ce mémoire était d'évaluer une nouvelle utilisation de technologie pour la production de matériel éducatif dans le contexte de la formation de pilotes novices. L'entraînement ciblait les comportements visuels de pilotes qui ont été identifiés à plusieurs reprises comme facteur commun causant les accidents de transport aérien. La technologie en question utilise la représentation d'un enregistrement de regard d'experts comme guide attentionnel superposé sur une vidéo d'entraînement, aussi appelé EMME en anglais.

L'article empirique est guidé par la question de recherche suivante : *Dans quelle mesure l'exposition au regard d'un expert durant une vidéo de formation impacte elle les performances visuelles et les performances de vol manuel de pilotes novices en entraînement?* Pour établir des hypothèses quant aux effets qui devraient être observés lors de l'exposition de novices au regard d'experts, l'article s'appuie sur la théorie cognitive de l'apprentissage multimédia et de la théorie sociale de l'apprentissage (Grusec, 1994; Mayer, 2014). Les deux mécanismes par lesquels ces théories nous laissent croire que l'EMME contribue à l'apprentissage sont par l'observation d'un comportement (le balayage visuel) qui précédemment était impossible ainsi que par le principe de signalement attentionnel. L'étude évalue à l'aide d'une expérience sur 23 pilotes novices, l'impact de l'EMME sur l'apprentissage. Les mesures du comportement visuel, de la télémétrie de la simulation de vol ainsi qu'un questionnaire sur la valeur perçue ont permis de vérifier les hypothèses. L'analyse des performances manuelles n'a pas permis de détecter une amélioration chez les participants lors de l'expérience. Toutefois, les résultats d'analyse des comportements visuels ainsi que de perception de valeur du matériel de formation ont clairement démontré un potentiel d'amélioration du processus de formation.

Contributions de l'étude

Cette étude s'inscrit de façon large dans les sciences cognitives et plus précisément comme une étude sur l'apprentissage de compétences techniques. Le présent mémoire s'ajoute également au répertoire croissant des études évaluant le potentiel de l'utilisation de la représentation du regard d'experts comme guide attentionnel, plus fréquemment nommé EMME dans la littérature. En fait, bien que l'amélioration des stratégies visuelles de pilotes experts a été étudiée (Lefrançois et al., 2021) le contexte spécifique de l'apprentissage de stratégies visuelles chez les élèves pilotes était absent de la littérature. L'expérience démontre que tout comme pour les pilotes experts, l'utilisation du regard d'experts est bénéfique au processus d'apprentissage. De façon plus générale, le présent mémoire constitue également une validation de la pertinence de l'EMME pour l'acquisition de compétences de pilotage, indépendamment du niveau d'expertise. Bien que certaines études remettent en question l'étendue des utilisations pertinentes de cette technologie, les résultats rapportés contribuent à valider la pertinence au sein du domaine aéronautique.

Outre les contributions scientifiques, la publication de résultats probants sur la valeur ajoutée par l'EMME pourrait également susciter le développement commercial de ce type de contenu de formation. En effet, la technologie des capteurs oculométrique continue d'être plus accessible et d'attirer l'attention de grandes compagnies. La production de matériel de formation pour un organisme détenteur de cette technologie pourrait potentiellement apporter beaucoup de valeur sans requis technologiques additionnels.

Limites et recherches futures

Les résultats nous permettent de constater que l'EMME est bénéfique au processus d'apprentissage de stratégies visuelles de pilotes novices et qu'elle augmente la valeur perçue. Cependant, tout comme pour la littérature concernant la technologie d'EMME, beaucoup de paramètres restent à déterminer. Par exemple, la représentation du regard d'expert est fréquemment sous forme de cercle rouge. D'autres formes ou couleurs seraient possiblement plus efficaces et moins exigeantes cognitivement. Une multitude de possibilités mériteraient d'être explorées par des études futures. En considérant l'implication des résultats pour l'ensemble de la littérature sur l'EMME, la présente recherche semble démontrer que des comportements visuels plus complexes bénéficient davantage de l'EMME. Il serait intéressant d'étudier cette hypothèse dans d'autres tâches requérant des comportements oculaires complexes. L'application de la représentation du regard d'expert pourrait également être évaluée lors d'une rediffusion ralentie pour permettre aux apprenants de mieux voir la séquence; ou bien, elle pourrait être présentée sans explications audio pour permettre aux apprenants de se concentrer sur une seule modalité instruction d'instructions, bien que cette hypothèse ne s'accorde pas avec la TCAM elle semble pertinente à analyser à priori. Pour ce qui est de l'application spécifique de l'EMME au pilotage, diversifier les tâches pour lesquelles l'EMME est utilisée serait intéressant. Bien que la phase de navigation semble plus réceptive à cette technologie, des manœuvres plus complexes ou des scénarios plus complexes devraient également être évalués.

Autrement, la présente recherche se trouve tout de même limitée par la méthode d'analyse des performances manuelles, la nature de l'évaluation de l'apprentissage et la taille de l'échantillon. Afin de produire une analyse des performances manuelles, un choix d'analyse sous-performant a été choisi afin d'accommoder les ressources limitées disponibles pour cette recherche. Ce choix d'analyse est possiblement un facteur ayant causé les résultats limités à propos de l'impact de l'EMME sur les performances de vol manuel. Bien que plus demandant, l'évaluation individuelle par un expert serait un choix judicieux pour les recherches futures. Cette approche fournirait une analyse équivalente à un examen en vol, le test ultime qui distingue les pilotes professionnels licenciés des pilotes novices. Ensuite, la nature d'une évaluation qui tente de mesurer l'apprentissage est vouée à être limitée puisque l'apprentissage se manifeste naturellement sur une durée plus grande qu'une étude transversale permet d'évaluer. Les ressources nécessaires pour effectuer une étude longitudinale étant beaucoup plus grandes que celles attribuées à ce mémoire, le choix de faire une étude transversale été fait. Les résultats démontrent bien le comportement d'imitation qui mène à un meilleur apprentissage selon la littérature, malgré cette limitation. Il serait tout de même intéressant de voir la progression sur une échelle de temps plus grande. Finalement, une étude qui porte sur l'apprentissage à un niveau spécifique d'une compétence peu commune entraîne forcément une grande difficulté au niveau du recrutement. Heureusement les résultats nous ont permis de démontrer les bénéfices de l'EMME, mais la précision des analyses et donc l'interprétation des résultats est limitée par le nombre réduit de participants. Si le processus devait être refait, conduire une première expérience similaire sur un bassin de population beaucoup plus grand pour acquérir de l'expérience avec la technologie et déterminer les paramètres, les plus efficaces permettraient d'approfondir les interprétations des résultats sans avoir à générer un grand échantillon au sein d'une petite population telle que les pilotes novices.

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