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Gaze Education in Piloting Training: A Way to Develop Adaptive Expertise

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In the field of aeronautical training, the interest of eye-tracking is growing. However, few studies have used it to educate ocular behavior [1, 2]. The dynamic and complex nature of the piloting situation seems to be one of the obstacles to the reuse of education methods used in the past (e.g. [3]) and in other field as part of learning more simple and static tasks (e.g. laparoscopic surgery, visual inspection). In the adaptive expertise framework, this article presents the results obtained through an original method of ocular education that we have developed to overcome the constraints posed by the nature of the piloting situation. The results show that thanks to a first learning period with our method, it is possible to accelerate the learning of new versions of the task (more complex and difficult). This opens up prospects for optimizing aeronautical trainings.

Keywords & Phrases: Eye Tracking, Gaze Education, Adaptive Expertise, Piloting, Training

1 INTRODUCTION

Eye-tracking devices are now widely used to study the perceptual processes underlying human performance in many areas. In the field of aviation, Ziv [1] and Peißl et al. [2] recently drew up a complementary review of research interested in studying the gaze during a piloting task. It appears from these reviews that eye-movement measures are mainly used for detecting performance decrements, assessing high-workload conditions or discriminating between experienced and less-experienced pilots. However, according to these authors, few studies have been interested in the benefit of using eye-tracking in a context of ab-initio education of pilot's gaze behavior.

This use of eye-tracking, described as promising, should prevent the acquisition of bad habits [3] and should ideally accelerate the development of pilotage expertise [4]. However, compared to many other fields, very few studies have undertaken to experimentally manipulate gaze behavior in the field of aviation. Whether in sport (e.g. basketball shoot [5]), video games [6], laparoscopic surgery [7], visual inspection of cargo aircraft [8] or printed circuit boards [9], this type of education has proven its effectiveness in optimizing the learning time of a task [10]. These studies revealed that, for an identical training time, people who received an education in gaze behavior showed superior performance, efficiency or stress resistance when performing the tasks concerned.

These methods generally aim to bring the student to reproduce the expert's visual scanpath known to be better (e.g. [8, 9]). In these fields, the studied situations are reproducible to the same or almost identical and it is also relevant to try to reproduce the expert's ocular behavior in the same situation. In contrast, the piloting task is carried out in a dynamic and complex environment [11] in which the situation evolves according to its own dynamic and, on which the human operator (here the pilot) can only have a partial control over it [12]. Consequently, through their decisions and actions, pilots create their own situations [13] that will be difficult, if not impossible, to reproduce identically. This difference is certainly one of the reasons that may have limited the application of these methods of

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gaze behavior education in the aviation field. Indeed, it seems to be not that relevant to ask a novice pilot to strictly reproduce the singular behavior adopted by an expert to respond to the unique and changing constraints encountered during the management of his piloting situation.

Moreover, the main risk to encourage student pilots to strictly reproduce specific visual scanpath is that, with the growing experience, they subsequently develop a limited ability to adapt to other cockpits or more complex flight conditions. This is what Hatano and Inagaki [14] named routine experts, which has been defined by Holyoak [15, p312] as being: people who "are able to solve familiar types of problems quickly and accurately, but who have only modest capabilities in dealing with novel types of problems". This is indeed a risk since pilots are asked to deal with familiar situations as well as those that are unprecedented to them. However, it is crucial that pilots are able to "invent new procedures derived from their expert knowledge" in order to avoid potential tragic consequences [15, p312]. This capability corresponds to de definition of adaptive experts as opposed to routine experts. Adaptive experts would have developed a deeper and more conceptual understanding of procedures while routine experts would have developed highly automated procedural skills [16]. Thus, in new situations, adaptive experts would be more effective than routine experts [17].

It is therefore interesting to investigate whether it is possible to propose a method of gaze education for novice pilots that can be used during the practice of a dynamic and complex task, and that can develop adaptive skills. To this end, since 2015, we have been developing an original method of gaze behavior education that can be used in dynamic and complex environments such as piloting an aircraft [18, 19]. This method is based on two main principles: i) online tracking and analysis of the participant's gaze behavior, and ii) real-time display of notifications (i.e., visual or sound feedbacks) based on behavioral rules defined to promote or reduce a particular gaze behavior. This method seems to avoid the acquisition of unwanted behaviors [20], and to develop capacities, such as time-interval distribution of visual attention [21]. In the context of reducing unwanted gaze behaviour, whenever the latter is identified, our method automatically and immediately gives feedback to the learner. This corresponds to an online feedback, which is given during the practice of the task and to an out of bounds feedback which is given at each detection of the unwanted behavior [22]. By giving this type of feedback, the learner should become aware of his or her gaze behavior, or at least, aware of the behavior to avoid. This metacognitive capacity is precisely one of the main factors that seems to favour the transfer of knowledge from one situation to another and which would be involved in the development of adaptive expertise [23]. Therefore, we make the hypothesis that, applied to pilot training, our educational method should allow pilot students to avoid the acquisition of bad gaze habits, to develop awareness of their gaze behavior, and that would ideally accelerate the development of an adaptive expertise of piloting.

This article presents an experiment which aims to start investigating this last hypothesis. In this experiment we evaluated the effects of our educational method on adaptive capacities in a context of changing difficulty and complexity of a task.

2 METHOD

In order to assess the adaptability which is the main characteristic of adaptive experts (see Carbonell et al. [23]), we used the method described by van Lehn and Chi [17] which measures the influence of a first learning on a second learning. This method therefore includes two successive learning periods, the second of which provides an assessment of the knowledge / skills acquired during the first period. There are, in this case, mainly two possible profiles of transfer of this knowledge / skill. First, the saving, which corresponds to the case where the first learning gives an advantage to a participant to start learning the second task (Figure 1 - Savings), a benefit that is preserved with the practice of the latter task. The second case, called acceleration of future learning (AFL), occurs when participants show an ability to learn the second task more quickly (Figure 1 - AFL). It is also possible for participants to show both saving and acceleration of future learning (Figure 1 - Both Savings and AFL).

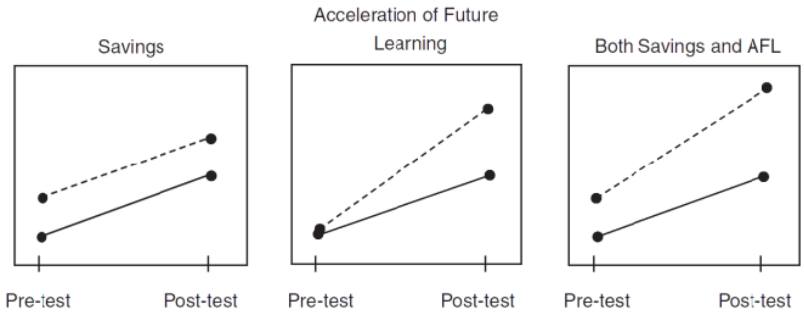

Figure 1: Graphical modeling of the different knowledge / skill transfer profiles [17].

For these two learning periods, we chose to vary the difficulty and complexity of the task. This type of change generally corresponds to situations in which adaptive expertise would be beneficial over routine expertise [24–27]. We thus hypothesize that participants benefiting from our gaze behavior education method should be superior in performance during the second learning period through better adaptation to change in the situation.

2.1 Participants

Thirty people from Air Base 701 of Salon-de-Provence (France) participated in our study. The sample consists of 11 women and 19 men aged between 20 and 37 years (M = 25, SD = 3.1). No participant had previously piloted an aircraft and all had normal or corrected vision. Participants were randomly assigned to three experimental groups: Control (Ctrl), SimpleTraining (ST), FullTraining (FT).

2.2 Material

The experiment was performed on a 22 inches Hyundai W22D screen with a resolution of 1680x1050 pixels. An Eye Tracker at 30Hz EyeTribe® was used to collect gaze data. Participants were seated 60cm from the screen, the EyeTribe was placed between the two, 50cm from the participant. A Trustmaster® T16000M joystick was used as an interaction device.

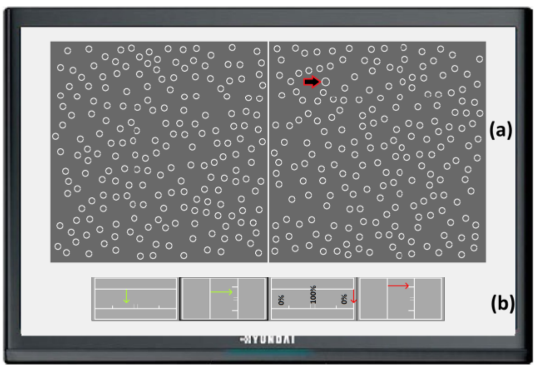

Figure 2: Screenshot of the microworld AbstractFlyingTask with the *targeting* (a) and the *monitoring* tasks (b). A black arrow shows the presence of a target in the right-hand area.

2.3 Learning environment and difficulty indices

The microworld AbstractFlyingTask (AFT; [20]) whose principle is to replicate the visual activity of piloting in visual flight (VFR) was chosen as environment for the study. It is composed of two tasks arranged one above the other, which we will respectively call the task of *targeting* and *monitoring*. The first (*targeting*) is a visual search task in which you have to look for a target (larger circle) among distractors (smaller circles) and answer in which area this target is. The second (*monitoring*) consists of managing the level of four gauges by keeping the different cursors (arrow) as close as possible to the central area. These cursors begin to drift randomly (Figure 2).

For the purposes of this experiment, we used several configurations varying in difficulty and complexity of the microworld AFT that we named: ID2, ID3 and ID3+ [19, pp139].

ID2 corresponds to the configuration used during the first learning period and is identical to that used in previous experiments [20]. There, the speed of movement by the participant of the cursors (*monitoring*) was faster (easier) than the other configurations, and the targets can be present on the left, right or nowhere (Figure 3).

ID3 corresponds to a configuration considered as more difficult, due to a slowing of the speed of movement by the participant of the cursors in the gauges. Finally, ID3+ corresponds to a complexification of the visual search task with the addition of the possibility to have both targets presented at the same time in the two zones (Figure 3).

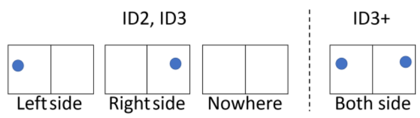

Figure 3: Diagram of possible cases for the targeting task of the AFT microworld for ID2, ID3, ID3 + configurations.

2.4 Task

The task was to detect targets (larger circles) among distractors, while managing the drift of four cursors in gauges over a period of 2 minutes.

2.5 Ocular behavior education method: tool and setting

We used a scenario that provides a notification that visually obscures the monitoring task every time it is watched for more than 2 seconds in a row ("2 seconds" scenario). Figure 4 recalls the rendering of this notification on the AFT microworld.

2.6 Protocol

The experiment took place over two days and included several sessions of two minutes each. The first day included experimental manipulation (first learning period) and was different for each group. The second day was identical for all of the three groups.

The first day consisted of a familiarization phase followed by the first learning period (ID2). It began with a first test (ID2 pre-test) to evaluate the initial performance on the ID2 configuration. Then, participants realized a training period which was different for each group: the FullTraining group

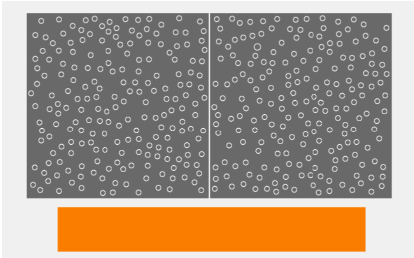

Figure 4: Screenshot of the AFT microworld during the appearance of the notification following the detection of a watch time greater than 2 seconds on the monitoring task.

realized six sessions of two minutes of training during which they received the notifications produced by our method of education thanks to the "2 seconds" scenario (Figure 4); The SimpleTraining group performed 6 training sessions freely, without any constraints or indications; the Control group did not perform any training session and did a 6-minute break. Finally, the participants carried out a last test (ID2 post-test) to evaluate their performance at the end of the session, without any notification.

The second day (24 hours later) consisted of (i) a retention test (retentionID2), performed to assess the presence of learning related to the training of the previous day, then (ii) the second learning period (ID3) including a first test on the ID3 configuration (pre-test ID3), followed by two training sessions and another evaluation (post-test ID3) on this same configuration. Lastly a transfer test was then performed on the ID3+ configuration of AFT. Figure 5 summarizes the experimental protocol.

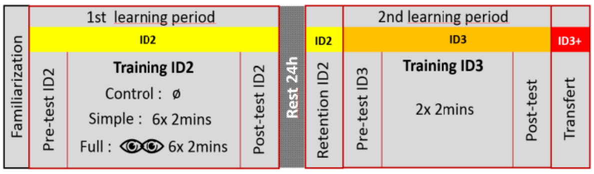

Figure 5: Experimental protocol performed

3 RESULTS

In this section, we first present a measure of control of the behavioral modification induced by our method of gaze behavior education (First learning period). Then, we present the analyses conducted according to the objective of this study, namely the assessment of the adaptability of people who have benefited from this method (Second learning period).

These analyses focused on two main measures: a behavioral measure (the time spent gazing at the *targeting* task) and a measure of the overall performance in the AFT microworld (i.e. general score given between 0 and 100). We favorized an overall performance measure rather than measuring the performance in each task (*targeting* and *monitoring*) separately. We were interested in the adaptability to new configurations as a whole, regardless of the participants' prioritization strategies, i.e. favoring one task over the other. Tasks were of equal importance in this study.

The behavioral measures analyses were only computed for the groups whose participants received training (SimpleTraining vs FullTraining) since the method of education used in this study aims at modifying the ocular behavior during practice. Therefore, we did not include the participants of the Control group in these analyses.

3.1 First learning period: behavioral modification

We analyzed the ratio of time spent gazing at the *targeting* task over total fixation time (Figure 6) with a 2x3 repeated-measures ANOVA with Group (SimpleTraining vs FullTraining) as a between group factor and Test (pre-testID2; post-testID2; retentionID2) as a within group factor. Results show a main effect of the Group factor ($F(1,18)$=11.76; MSE=2291.7; p=.003), a main effect of the Test factor ($F(2, 36)$=12.43; MSE=608.2; $p < .001$) on the behavioral measure and an interaction effect of Group x Test ($F(2,36)$=3.93; MSE=192.5; p=.028).

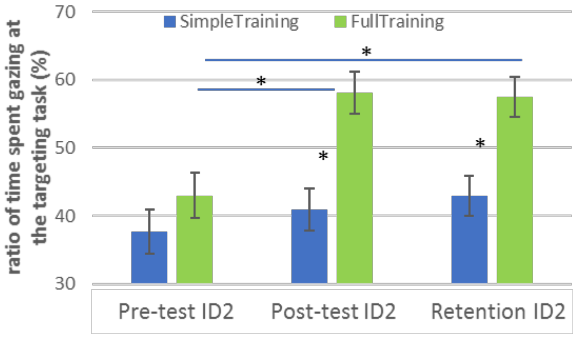

Figure 6: Graph showing the ratio of time spent gazing at the *targeting* task over total fixation time for the SimpleTraining and FullTraining groups during pre-testID2, post-testID2 and retentionID2.

Newman-Keuls post-hoc tests revealed no difference between the SimpleTraining group (M=37.68, SE=3.28) and the FullTraining (M=43.03, SE=3.08) for pre-testID2 (p>.1). No difference was observed within the SimpleTraining group, neither between pre-testID2 and post-testID2 (M = 40.99, SE = 3.11; p>.1) nor between post-testID2 and retentionID2 (M=42.93, SE=2.98; p>.1), nor between pre-testID2 and retentionID2 (p>.1). The SimpleTraining group seems to have maintained the same behavior during the training period.

Conversely, for the FullTraining group, we observed an increase in the ratio of time spent gazing at the *targeting* task between pre-testID2 and both post-testID2 (M=58.13, SE=3,11; p<.001) and retentionID2 (M=57.52, SE=2.98; p<.001). No difference was observed between post-testID2 and retentionID2 in this group (p>.1). The FullTraining group seems to have durably modified its ocular behavior during the training period.

Finally, post-hoc analyses revealed that the FullTraining group spent significantly more time gazing at the *targeting* task compared to the SimpleTraining group in the post-testID2 (p = .003) and retentionID2 (p=.006) conditions.

3.2 Second learning period: adaptability

We first analyzed the overall performance in the AFT microworld measure (Figure 7) for the three groups during the ID3 and ID3+ configuration tests. Therefore, we performed a 3x3 repeated-measures ANOVA with Group (Control; SimpleTraining; FullTraining) as a between group factor and Test (pre-testID3; post-TestID3; TransfertID3+) as a within group factor. Results show a main effect of the Group factor ($F(2,27)$=6.17; MSE=1916.1; p=.006) and a main effect of the Test factor ($F(2,54)$=15.10; MSE=543.3; p<.001). We also observed an interaction effect of Group x Test ($F(4,54)$=2.80; MSE=100. 9; p=.035).

The results of the planned comparisons reveal that the two groups that performed training sessions during the first learning period (i.e. SimpleTraining and FullTraining) had a better overall performance compared to the Control Group in the pre-testID3 ($F(1,27)$=7.92; MSE=1390.32; p=.009)

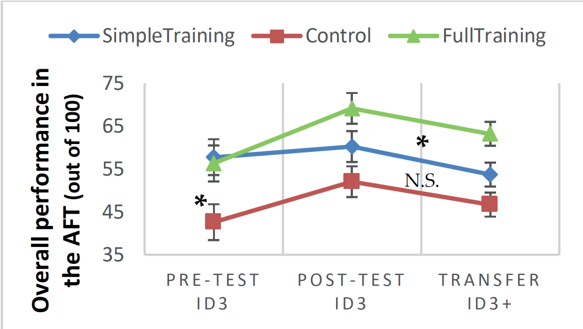

Figure 7: Graph showing the overall performance in the AFT microworld for the three experimental groups (Control, SimpleTraining, FullTraining) during pre-testID3, post-testID3 and transfertID3+.

Moreover, results show that the FullTraining group had a significantly better performance in the post-testID3 and the transfertID3+, compared to the SimpleTraining group ($F(1,27)$=4.60; MSE=845.90; p=.041). Finally, no difference was revealed by the planned comparisons between the performance of the SimpleTraining group and the Control group in the post-testID3 and the transfertID3+ ($F(1,27)$=3.14; MSE=578.33; p=.087). It seems that the FullTraining group was able to better adapt to these new configurations (ID3, ID3+) compared to the other groups.

Ratio of time spent gazing at the targeting task. In order to deeper understand the influence of the first learning period on the previous measure of the overall performance, we analyzed the ratio of time spent gazing at the *targeting* task for the more difficult and complexes tests (ID3, ID3+). The control group was not included in this analysis. To assess this behavior measure, we performed a 2x3 repeated-measures ANOVA with Group (SimpleTraining; FullTraining) as a between group factor and Test (pre-testID3; post-TestID3; TransfertID3+) as a within group factor. Results show a main effect of the Group factor ($F(1,18)$=5.12; MSE=1605.1; p=.036) as well as an effect of the Test factor ($F(2, 36)$=24.18; MSE=876; p<.001). However, we did not oberve an interaction effect of Group × Test ($F(2,36)$=1.92; MSE=69.5; p>.1).

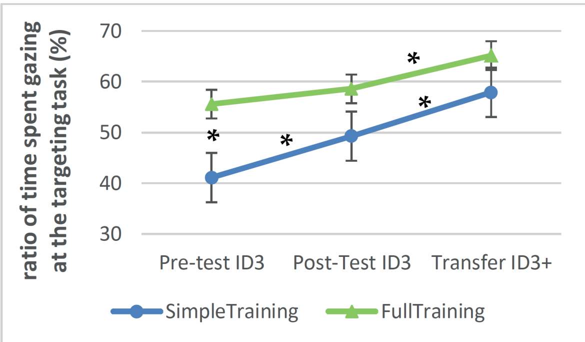

Figure 8: Graph showing the ratio of time spent gazing at the *targeting* task over total fixation time for the SimpleTraining and FullTraining groups during pre-testID3, post-testID3 and transfertID3+.

Newman-Keuls post-hoc tests revealed that the FullTraining group spent significantly more time gazing at the *targeting* task compared to the SimpleTraining in the pre-testID3 (p=.022). Then, during the post-testID3 after the training sessions, no significant difference was observed with the pre-testID3 for the FullTraining group (p>.1), while the SimpleTraining group significantly increased the time spent gazing at the *targeting* task compared to the pre-testID3 (p=.021).

4 DISCUSSION

In this study, we first observed that participants naturally tend to spend 40% of their time gazing at the targeting task.Without any intervention, the participants who trained freely (SimpleTraining group) maintained this behavior during the post-testID2 and retentionID2. The learning environment offered to the FullTraining group, based on our method of gaze behavior education, durably modified the gaze behavior of the participants in this group. After only 12 minutes of training (6x2mins), they were significantly more interested in the targeting task with about 60% of the gaze fixation time in post-TestID2 and maintained this behavior, after 24 resting hours, during the retentionID2 test. These results corroborate those of our previous study [20] and provide further evidence that our educational method can bring about to lasting changes in gaze behavior during the practice of a dynamic and complex situation.

Another result of this experiment concerns the second learning period on the ID3 configuration of the AFT microworld. The aim of this period was to assess the influence of the first learning period on the ability to adapt to a second, more difficult configuration. Unsurprisingly, the groups whose participants received training on the first day (i.e., SimpleTraining and FullTraining) performed better than the Control group in the pre-test ID3. Nevertheless, while this second training period was identical for the three experimental groups, all groups did not show a similar evolution in their performance and gaze behavior. Figure 9 illustrates the different changes in overall performance in the AFT microworld for each group during the pre-test and post-test of the ID3 configuration.

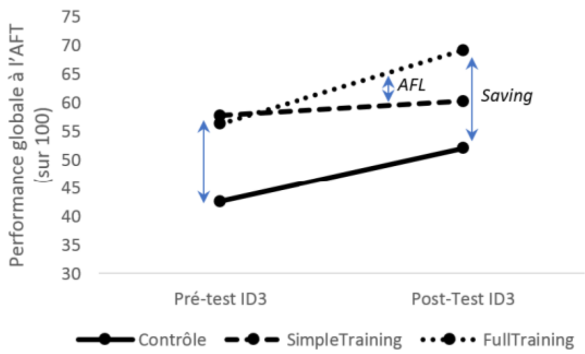

Figure 9: Graph showing the overall performance in the AFT microworld for the three experimental groups (Control, SimpleTraining, FullTraining) during the second learning period (pre-testID3, post-testID3). The effects of “Saving” and “Acceleration of future learning” (AFL) are symbolized.

In accordance with the theory of adaptive expertise [17], the FullTraining group has a higher rate of progression than the SimpleTraining group.We are therefore in the presence of “Acceleration of Future Learning (AFL)”. The gaze behavior education received during the first training period allows the FullTraining group participants to adapt more quickly to this new microworld configuration and to quickly achieve better performance than the SimpleTraining group. In addition, participants in the SimpleTraining group do not maintain their superiority over the Control group during the post-testID3 despite having trained on the first day. Compared to the Control group, we are therefore in the presence of “saving” only for the FullTraining group.

These results can be partly explained by the analysis of the evolution of gaze behavior of the Simple-Training and FullTraining groups. Indeed, the results do not reveal any difference in the gaze behavior of the participants in the FullTraining group between the pre-testID3 and post-testID3. This means that they have not changed, or very little, their strategy for distributing their visual attention. In contrast, the results show a significant increase in the ratio of time spent gazing at the targeting task for the participants in the Simple Training group. While the participants of the SimpeTraining group had kept an almost identical distribution of their gaze from the pre-testID2 to the pre-testID3 (40% of time spent gazing at the targeting task) the increased difficulty of the task forced them to change. Such a change in strategy requires cognitive resources and on a short training, it seems to have an influence on performance. It is indeed common that in situations involving a high cognitive load, if people are not guided, the experience they develop through trial and error seems to lead them to suboptimal strategies that will be difficult to modify later [28, 29]. Despite the training sessions, the SimpleTraining group is the only one that does not improve its performance. This implies that the strategy naturally adopted by the participants of the SimpleTraining group during the simplest configuration (ID2) can be considered as a bad habit. Once installed, it would be costly to change and would be a burden in adapting to the ID3 configuration of the AFT microworld.

Conversely, our method of gaze behavior education avoided this bad habit and then allowed the participants in the FullTraining group to better adapt to the new configurations. The results of the evaluations of the ID3+ configuration revealed that on this more difficult and complex configuration, the FullTraining group is once again superior to the other two groups. The gaze behavior education that the FullTraining group participants received was therefore also an asset for the practice of this alternative version (ID3+) of the AFT microworld.

5 CONCLUSION

This experimentation demonstrates, on the one hand, that the education of gaze behavior in a dynamic and complex environment is possible. It also opens the way to a new way of educating gaze behavior that is a solid alternative to strictly learning an expert's visual scanpath. This is in line with the hypotheses in the literature since it would avoid the acquisition of bad habits [3] and it would seem to accelerate the development of expertise [4], an expertise that would be adaptive and not routine.

On the other hand, this experiment encourages us to further explore the possibilities and limitations of using our educational method based on two simple technical principles: i) online tracking and analysis of the participant's gaze, and ii) real-time display of notifications (i.e., visual or sound feedback) based on gaze analysis rules defined to promote or reduce a particular ocular behavior.

We now wish to integrate our method on flight simulators into the ab-initio training of pilot students of the French Air Force. This should help trainers to identify the natural visual strategies of student pilots. Finally, it would also allow to study if providing notifications with our educational method improves the development of their expertise through the earlier acquisition of adequate gaze behavior.

REFERENCES

[1] Gal Ziv. Gaze behavior and visual attention: A review of eye tracking studies in aviation. *The International Journal of Aviation Psychology*, 26(3-4):75–104, 2016.

[2] Sylvia Peißl, Christopher D Wickens, and Rithi Baruah. Eye-tracking measures in aviation: a selective literature review. *The International Journal of Aerospace Psychology*, 28(3-4):98–112, 2018.

[3] Paul A Wetzel, Gretchen M Anderson, and Barbara A Barelka. Instructor use of eye position based feedback for pilot training. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 42, pages 1388–1392. SAGE Publications Sage CA: Los Angeles, CA, 1998.

[4] Andrew H Bellenkes, Christopher D Wickens, and Arthur F Kramer. Visual scanning and pilot expertise: the role of attentional flexibility and mental model development. *Aviation, space, and environmental medicine*, 1997.

[5] Samuel J Vine and Mark R Wilson. The influence of quiet eye training and pressure on attention and visuo-motor control. *Acta psychologica*, 136(3):340–346, 2011.

[6] Kimron L Shapiro and Jane E Raymond. Training of efficient oculomotor strategies enhances skill acquisition. *Acta Psychologica*, 71(1-3):217–242, 1989.

[7] Mark R Wilson, Samuel J Vine, Elizabeth Bright, Rich SW Masters, David Defriend, and John S McGrath. Gaze training enhances laparoscopic technical skill acquisition and multi-tasking performance: a randomized, controlled study. *Surgical endoscopy*, 25(12):3731–3739, 2011.

[8] Sajay Sadasivan, Joel S Greenstein, Anand K Gramopadhye, and Andrew T Duchowski. Use of eye movements as feedforward training for a synthetic aircraft inspection task. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 141–149, 2005.

[9] Deepthi Nalanagula, Joel S Greenstein, and Anand K Gramopadhye. Evaluation of the effect of feedforward training displays of search strategy on visual search performance. *International Journal of Industrial Ergonomics*, 36(4):289–300, 2006.

[10] Samuel J Vine, Rich SW Masters, John S McGrath, Elizabeth Bright, and Mark R Wilson. Cheating experience: Guiding novices to adopt the gaze strategies of experts expedites the learning of technical laparoscopic skills. *Surgery*, 152(1):32–40, 2012.

[11] H Eyrolle, C Mariné, and S Mailles. La simulation des environnements dynamiques: intérêts et limites. *Cellier, JM, De Keyser, V., Valot, C., La gestion du temps dans les environnements dynamiques. PUF, Paris*, pages 103–121, 1996.

[12] J.-M. Hoc and G. Plee, editors. *Délai de réponse, planification et facteurs de coût en situation dynamique*. Ergonomie de la conduite des processus industriels. Institut National de Recherche et de Sécurité, Paris, France, 1996.

[13] Ward Edwards. Dynamic decision theory and probabilistic information processings. *Human factors*, 4(2):59–74, 1962.

[14] Giyoo Hatano and Kayoko Inagaki. Two courses of expertise. *Research and Clinical Center for Child Development, Annual Report*, 6:27–36, 1984.

[15] Keith J Holyoak. 12 symbolic connectionism: toward third-generation theories of expertise. *Toward a general theory of expertise: Prospects and limits*, page 301, 1991.

[16] Eleanor M Smith, J Kevin Ford, and Steve WJ Kozlowski. Building adaptive expertise: Implications for training design strategies. 1997.

[17] Kurt van Lehn and Min Chi. Adaptive expertise as acceleration of future learning. *Adaptive technologies for training and education*, pages 28–45, 2012.

[18] Emilien Dubois, Colin Blättler, Cyril Camachon, and Christophe Hurter. Eye movements data processing for ab initio military pilot training. In Rui Neves-Silva, Lakhmi C. Jain, and Robert J. Howlett, editors, *Intelligent Decision Technologies*, pages 125–135, Cham, 2015. Springer International Publishing.

[19] Emilien Dubois. *Optimisation de la formation des pilotes par l'éducation du comportement oculaire*. PhD thesis, Toulouse, ISAE, 2017.

[20] Emilien Dubois, Cyril Camachon, Colin Blättler, and Christophe Hurter. Évaluation du dispositif pigat (pilotgazetrainer) pour l'entraînement des stratégies visuelles d'élèves pilotes. 2016.

[21] Grégory Froger, Colin Blättler, Emilien Dubois, Cyril Camachon, and Nathalie Bonnardel. Time-interval emphasis in an aeronautical dual-task context: A countermeasure to task absorption. *Human factors*, 60(7):936–946, 2018.

[22] Richard A Schmidt and Bettina Debû. *Apprentissage moteur et performance*. Vigot Paris, 1993.

[23] Katerina Bohle Carbonell, Renée E Stalmeijer, Karen D Könings, Mien Segers, and Jeroen JG van Merriënboer. How experts deal with novel situations: A review of adaptive expertise. *Educational Research Review*, 12:14–29, 2014.

[24] Elizabeth Allworth and Beryl Hesketh. Construct-oriented biodata: Capturing change-related and contextually relevant future performance. *International Journal of Selection and Assessment*, 7 (2):97–111, 1999.

[25] Gerhard Blickle, Jochen Kramer, Paula B Schneider, James A Meurs, Gerald R Ferris, Jan Mierke, Alexander H Witzki, and Tassilo D Momm. Role of political skill in job performance prediction beyond general mental ability and personality in cross-sectional and predictive studies 1. *Journal of Applied Social Psychology*, 41(2):488–514, 2011.

[26] Barbara Griffin and Beryl Hesketh. Adaptable behaviours for successful work and career adjustment. *Australian Journal of psychology*, 55(2):65–73, 2003.

[27] Gilad Chen, Brian Thomas, and J Craig Wallace. A multilevel examination of the relationships among training outcomes, mediating regulatory processes, and adaptive performance. *Journal of Applied Psychology*, 90(5):827, 2005.

[28] Daniel Gopher, Maya Well, and Tal Bareket. Transfer of skill from a computer game trainer to flight. *Human factors*, 36(3):387–405, 1994.

[29] Mark A Foss, Monica Fabiani, Amir M Mané, and Emanuel Donchin. Unsupervised practice: The performance of the control group. *Acta Psychologica*, 71(1-3):23–51, 1989.