Time-Interval Emphasis in an Aeronautical Dual-Task Context: A Countermeasure to Task Absorption

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Objective: We tested a training method intended to prevent unsafe aeronautical behavior (i.e., too much time spent gazing inside the cockpit) induced by the modern cockpit, by teaching individuals to perform a task complementing the see-and-avoid mandatory safety task within a limited time interval.

Background: Aeronautical activities led crews to perform several tasks simultaneously in an ergonomic environment under constant change. *See and avoid* remains one of the main safety tasks during visual flight. However, modern cockpits induce absorption and impair performance of this safety task. Many laboratory studies showed the relevance of training methods for managing dual-task situations and estimating time intervals.

Method: A specific virtual environment was developed to expose participants to a dual-task situation in which time-interval emphasis was provided in real time. Two types of emphasis training were tested: a permissive one that allowed participants to pursue the inside-cockpit task beyond the time limit and a nonpermissive one that did not.

Results: The best time-interval acquisition, with retention up to 24 hr later, was observed in the nonpermissive condition, but task performances immediately after the training sessions were equivalent across conditions.

Conclusion: Time-emphasis training appears to be an efficient means of promoting absorption resistance while preserving task performance. Transferability of time-interval estimation skills has yet to be tested.

Application: Most areas of application for absorption resistance (aviation, shipping, rail, road, etc.) could benefit from this type of training to manage multitask situations.

Keywords: dual task, learning, interval timing, simulation-based skill acquisition, absorption

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INTRODUCTION

See and avoid (i.e., detecting potentially dangerous items in the air) is considered to be one of the main safety tasks in aeronautical activities. Crew members must simultaneously manage this task and other complex tasks in a dynamic environment. A situation is defined as *dynamic* if it can change without any human input and has an unpredictable time course (Hoc, Amalberti, Cellier, & Grosjean, 2004). For this reason, flying an aircraft requires constant attention work (Boy, 2005). However, modern cockpits (e.g., glass cockpit) have features (Funk et al., 1999; Parasuraman, & Riley 1997) that can disturb attention allocation. The goal of the present study was thus to test a pedagogical countermeasure favoring the see-and-avoid safety task.

Aeronautical situations are as dynamic outside the cockpit, be it within the natural environment (weather, birds) or the human-made environment (air traffic), as they are inside (engine failure). Crews must focus their attention according to these dynamic situations, with patterns of attention (Boy, 2005) adapted to the outside and inside worlds. The allocation of attention can be disrupted by the mass of data provided by the modern cockpit, which can, for instance, impair the storage of important information (e.g., Casner, 2006). One of the consequences of this absorption is that attention is focused inside the cockpit for too long (Johnson, Wiegmann, & Wickens, 2006; Rudisill, 1994). Indeed, the National Transportation Safety Board (2010) and Federal Aviation Administration both recommend providing specific education and training to overcome glass cockpit issues (Schumacher, Blickensderfer, & Summers, 2005).

In the present study, we examined the acquisition of a rule (i.e., no more than 2 s of head-down time) taught in aviation schools as a countermeasure to avoid excessive focus of attention inside the cockpit. This rule is based on the *Aeronautical Instruction Manual* (8.1.6.C) recommendation that "the time a pilot spends on visual tasks inside the cabin should represent no more than 1/4 to 1/3 of the scan time outside" (Federal Aviation Administration, 2017). Flight instructors have two main ways of signaling 2-s rule violations. The first is auditory (e.g., "Look outside") and the second, visual (e.g., putting a map in front of the head-down display, forcing the student crew member to look up and look outside). We wanted to test a method for training gaze patterns in a simulated environment replicating aspects of aeronautical activity. In this simulated environment, we automated the rule violation emphasis. This study was a part of a process to develop a tool for teaching attention management in aeronautics.

We therefore explored two variants of a method for teaching crews the ability to estimate time intervals in a simplified environment mimicking flight activity. This method is based on emphasis, which was shown to induce efficient learning in a dynamic situation (Gopher, Weil, & Siegel, 1989), and exclusively targets the amount of time spent head down. The first emphasis that we tested was permissive in that it allowed participants to maintain their gaze on the head-down task (HDT), as is the case when it was an auditory warning given by the flight instructors. The second emphasis was nonpermissive in that it did not allow participants to maintain their gaze on the HDT, as is the case when flight instructors place a map in front of the head-down display.

Theoretical works on learning, dual tasks, and interval timing have allowed acquisition of the 2-s rule to be optimized. For Sweller (1994), the process of learning enables individuals to store automated schemas in long-term memory. A *schema* is a cognitive construct that organizes items of information according to the manner with which they will be processed. In the aeronautical context, where crews have to divide their visual attention between the inside and the outside of the cockpit, visual attention procedures are given a spatiotemporal organization by a schema specific to that situation. For example, whereas novices have to start the visual circuit by consciously thinking about gazing inside, gazing outside, and so on, experienced crew members can effortlessly perform this visual circuit (Rassmussen, 1983; Sweller, 1994). *Automatization* (Logan, 1988) is the outcome of a gradual process based on repetition (i.e., extensive practice). For Logan (1988), when novices repeat a task, they continue to use a general algorithm until they find a solution to that task, which is then stored in long-term memory. Thereafter, if they encounter a similar task, they can skip the general algorithm process and directly retrieve the solution from long-term memory. This requires fewer attentional resources and is also quite time effective. Schema-based processing allows individuals to deal with large amounts of information by binding separate items via a chunking mechanism (Gobet & Simon, 1996). The automatization process allows individuals to deal with schemas without overloading working memory (Logan, 1988; see also Baddeley's episodic buffer [2000]). It also allows them to manage additional tasks within the same period of time.

Nevertheless, according to Wickens (2002), two tasks that simultaneously demand the same resources (e.g., two visuomotor tasks) cannot be performed in parallel. Switching from one task to the other is the only way of dealing with this dual-task situation. This was the same for our situation, where the see-and-avoid task and inside cockpit task could not be performed in parallel. Although the two tasks rely on two specific and independent mechanisms, they are linked by a third mechanism: coordination. In our study, this coordination involved limiting the length of time that was spent performing the inside cockpit task.

Strobach, Salminen, Karbach, and Shubert (2014) assumed that repeated exposure to switching in a dual-task situation leads to the combined instantiation of sets of information from both tasks and, hence, to improved coordination for simultaneously managing the two tasks. This coordination was dubbed *intertask coordination* by Liepelt, Strobach, Frensch, and Schubert (2011).

If the 2-s rule is to be respected, temporal regularity needs to be included in intertask coordination to achieve the required spatiotemporal organization of attentiveness. This rule is based on the ability to correctly estimate 2 s while performing different tasks, specifically HDTs (inside the cockpit). This skill, which is related to the ability to estimate a time span, is defined by Taatgen, van Rijn, and Anderson (2007) as *time-interval estimation* (TIE). These authors showed that TIE can be learned (see also Matthews & Meck, 2014; Penney, Allan, Meck, & Gibbon, 1998; van Rijn, 2016; Vierordt, 1868) and automatized in a simultaneous dual-task situation. TIE acquisition follows the learning processes described by Sweller (1994), based on the acquisition and automatization of schema.

Taken together, these findings for dual-task learning and TIE suggest that extensive training could lead TIE to be integrated into intertask coordination.

Present Study

The purpose of the present study was thus to test the effect of permissive versus nonpermissive notification on the modification of the gazing pattern based on integration of the 2-s rule. To optimize the acquisition of the 2-s rule, we developed two tasks that represented simplified flight activity: a head-up task (HUT) representing the see-and-avoid visual search activity and a HDT representing the management of a dynamic system. The HUT objective was to find a larger circle (target) among a set of smaller ones (distractors). The aim of the HDT was to keep arrows in the middle of the gauges. This virtual environment was associated with an eye tracker, which allowed us to record HDT fixation time in real time. To adapt the training to the learning mechanism, these two tasks were administered simultaneously and repeated several times. In the same vein, whenever participants broke the 2-s rule, they were systematically notified in real time (visual time-interval emphasis). As such, systematicity is impossible during in-flight instruction; participants were more frequently exposed to notifications in the study than in real flight.

Systematic emphasis on 2-s violations was previously tested during a simulated flight. When Dubois, Blättler, Camachon, and Hurter (2015) studied the natural behavior of French Air Force cadet pilots, they found that 40% of their gaze activity took place outside the cockpit, but this proportion increased to 60% when they were exposed to rule violation emphasis. Neither long-term acquisition of this modified behavior nor attentional performance in terms of managing the outside world was measured. The present study was designed to take account of these two limitations. Attentional behavior was measured via HUT and HDT performances to see whether participants performed both tasks well. To objectively assess the acquisition of this modified behavior in long-term memory, we measured the effects of emphasis training immediately after the training sessions and again 24 hr later. These two test sessions were conducted without emphasis.

The goal of this study was to assess whether specific real-time emphasis can lead to the reproduction of an interval of a given duration in a dynamic dual-task context that mimics flight activity. We tested two types of real-time emphasis intended to ensure that pilots adhere to the aeronautical recommendation of no more than 2 s of head-down time: permissive emphasis and nonpermissive emphasis. Participants in the control condition were exposed to the same recommendation but without any emphasis. We then compared the effects of these different types of emphasis on HUT and HDT performances, the respect of the 2-s rule, and the amount of fixation time for the HUT.

Hypotheses

If the 2-s rule was indeed integrated, then we would observe greater adherence to the 2-s rule in the emphasis groups (Hypothesis 1). In line with Dubois et al. (2015), we expected to see longer fixation times allocated to the HUT than the HDT in the emphasis groups (Hypothesis 2).

We assumed that the dual-task training would lead to improved performances on HUT and HDT (Hypothesis 3). Nevertheless, given Hypothesis 2, we expected the experimental groups to perform better on HUT than on HDT (Hypothesis 4).

METHOD

Participants

A total of 120 participants were randomly assigned to three groups. Data from 12 participants could not be used (participants failed to return 24 hr later). The control group (CG) consisted of 40 participants (mean age = 19.5 years, range = 17–26 years). The permissive emphasis group (PG) consisted of 32 participants (mean age = 19.2 years, range = 17–28), whereas the nonpermissive group (NPG) consisted of 36 participants (mean age = 19.8 years, range = 17–29). Participants had never flown an aircraft before, and all had normal or corrected-to-normal vision.

Apparatus and Stimuli

Stimuli were presented on a 22-in. Hyundai W220D color monitor with 1,680 × 1,050 resolution. Experiments were carried out with the Abstract Flying Task (AFT) microworld (described later), coupled with PilotGaze Trainer software allowing two tasks to be performed simultaneously to mimic aeronautical activity (for a complete description of the apparatus, see Dubois, Camachon, Blättler, & Hurter, 2016).

Microworld AFT was designed to reproduce some aspects of flying an aircraft (dynamic, complex, uncertain), especially the visual aspect (scanning and monitoring). The HUT represented the see-and-avoid activity, and the HDT represented system monitoring. The HUT and HDT both took place in the visuospatial modality (Wickens, 2002).

PilotGaze Trainer software allows emphasis to be conveyed according to particular eye movement behavior, defined in our study as gazing at the HDT location for >2 s. Participants interacted with the microworld and responded to the two tasks using a Logitech Extreme 3D Pro joystick. They were seated 60 cm from the screen. Eye movement data were collected via EyeTribe (30-Hz sampling rate) from a viewing distance of 60 cm.

Presentation of AFT microworld. Two visuomotor tasks were presented simultaneously (see Figure 1): one HUT and one HDT. The HUT, which simulated visual searching, had to be performed at the same time as the HDT, which probed monitoring and managing system parameters.

Head-up task. The HUT was a surrogate reference task (e.g., Mattes & Hallen, 2009), where the objective was to find a larger circle (target) among a set of smaller ones (distractors). There were always 400 circles in total, but the target was present in only some of the trials. The outline of each circle was 3 pixels thick, and the diameter was either 20 pixels (35 min of arc) for the distractors or 26 pixels (44 min of arc) for the target. It was impossible to perceive the target preattentively, as the target and distractors had the same shape and the same color (Bertin, 1973; Conversy, 2015).

The target appeared randomly on either side (left or right) or was absent altogether from the split head-up screen. Participants had to respond as fast as possible by pressing one of the three buttons on the upper part of the joystick with their thumb (left button if the target was in the left screen, right button if the target was in the right screen, middle button if there was no target). When participants made a response, yellow feedback was provided, followed by a new trial. If 9,000 ms elapsed without the participant making a response, red feedback was provided, followed by a new trial. The minimum number of trials in a single session was 14. The number of trials increased with the number of responses by the participant.

Head-down task. This task was inspired by one of the pilot selection tests at the National School of Civil Aviation (Matton, Paubel, Cegarra, & Raufaste, 2016). It consisted of four gauges, each with an arrow. At the beginning of each session, all the arrows were located at the midpoint. They then began to drift randomly to one of the ends. The aim was to keep all the arrows at the midpoint. To select a gauge, participants had to move a black selector on the gauge with a wrist rotation (z-axis), then click the trigger. Once the gauge had been selected, the arrow could be repositioned by movements in the x- or y-axis. To unselect a gauge, participants had to click on the trigger again.

Procedure and Design

Participants had to perform the HUT and HDT simultaneously. They could respond in any order that they liked. Both tasks started at the same time and ran for the entirety of the session, completely independent of each other.

Experimental instructions were as follows: (1) Perform both tasks as well and as quick as possible, and (2) do not spent more than 2 s at a time on the HDT.

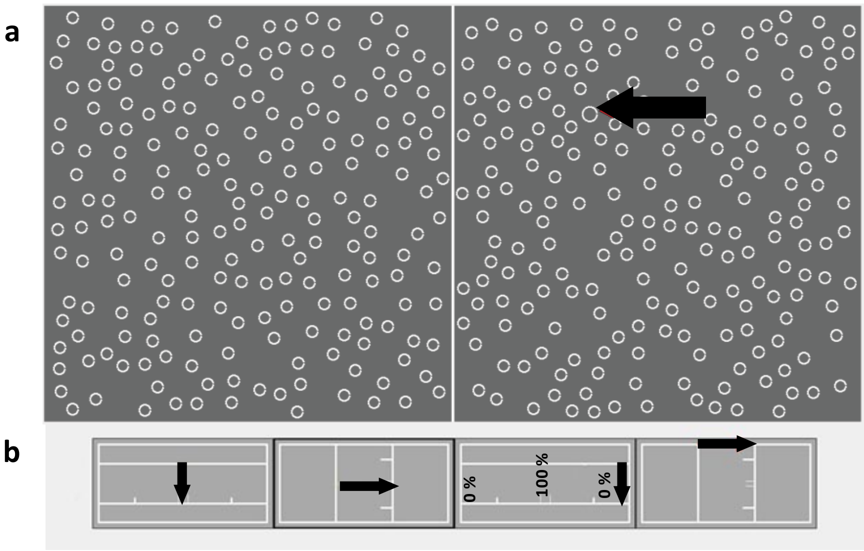

Figure 1. Screenshot of the Abstract Flying Task microworld. (a) The head-up task target is indicated by a black arrow. (b) The head-down task is in a configuration where both gauges on the right are at zero and both gauges on the left are falling.

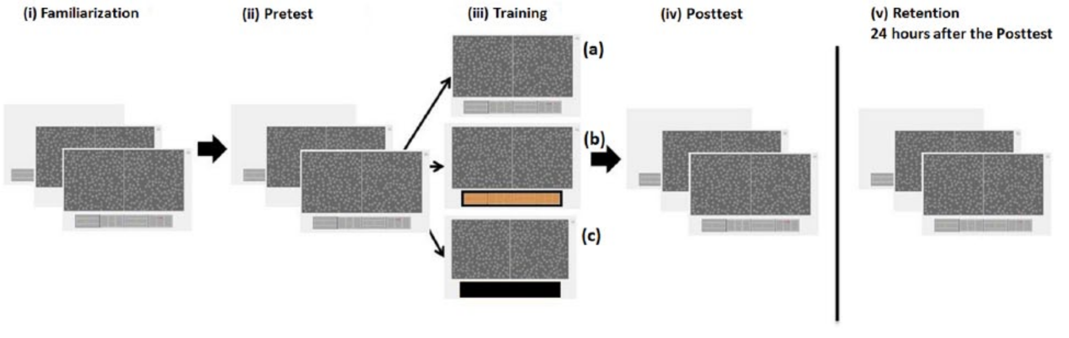

Figure 2. Procedure and design of the experiment in five phases. There was (a) no mask for the control group, (b) a transparent mask for the permissive emphasis group, and (c) an opaque mask for the nonpermissive group.

Participants were randomly divided into three groups: CG, PG, and NPG. The experiment took place over five phases: (1) familiarization, (2) pretest, (3) training sessions, (4) posttest, and (5) retention test (administered 24 hr after the posttest; see Figure 2).

During the familiarization phase (1), participants underwent 30 s of training on each task: first the HDT alone, then the HUT alone, and finally the HUT and HDT simultaneously.

During the test phases (2, 4, 5), participants in all three groups had to perform the HUT and HDT without any emphasis. These test phases each lasted 2 min.

The training phase (3) consisted of a succession of six 2-min training sessions where the HUT and HDT had to be performed simultaneously. Participants could respond in any order they liked. The emphasis (permissive or nonpermissive) was presented after 2,000 ms spent gazing exclusively at the HDT location (in accordance with the 2-s rule), in the form of an orange mask over the whole HDT. For PG, this mask was transparent and allowed the HDT to be continued. For NPG, it was opaque, making it impossible to pursue the HDT. There was no mask for the CG.

Performance measurement. The number of 2-s rule violations (>2,000 ms spent fixating the HDT) and the time spent on the HUT and HDT were recorded.

HUT performance was the percentage of correct answers out of the total number of trials. HDT performance was rated out of 100 (25 per gauge) and corresponded to the mean score in the test session. The maximum score (25) for each gauge was achieved when the arrow remained in the middle of the gauge and decreased linearly as the arrow moved away, falling to 0 when it reached the end of the gauge. To measure overall performance, we averaged the mean percentage of correct answers to the HUT and mean HDT performance.

RESULTS

All analyses of variance (ANOVAs) were conducted with time emphasis as a between-groups factor (CG, PG, NPG) and with learning (pretest, posttest, retention) as a within-group factor. Separate ANOVAs were conducted for the mean number of 2-s rule violations, the mean percentage of HUT fixation time, overall performance, and the HUT and HDT performances.

Two-Second Rule Violations

An ANOVA on the number of 2-s rule violations (see Figure 3) revealed a significant learning effect, $F(2, 210) = 18.67$, $MSE = 972.57$, $p < .0001$, a significant time emphasis effect, $F(2, 105) = 3.79$, $MSE = 573.66$, $p = .026$, and a significant interaction between the two, $F(4, 210) = 2.77$, $MSE = 144.14$, $p = .028$. Tukey's honest significant difference (HSD) post hoc analyses were conducted.

For the learning effect, the following pairs were significantly different ($p < .05$): pretest ($M = 17.15$, $SD = 10.08$) versus posttest ($M = 12.87$, $SD = 9.66$) and pretest versus retention test ($M = 11.37$, $SD = 8.47$).

For time emphasis effect, the following pair was significantly different ($p < .05$): CG ($M = 16.008$, $SD = 9.99$) versus NPG ($M = 11.53$, $SD = 9.79$). There was a nonsignificant difference between PG ($M = 13.58$, $SD = 8.72$) and the other groups.

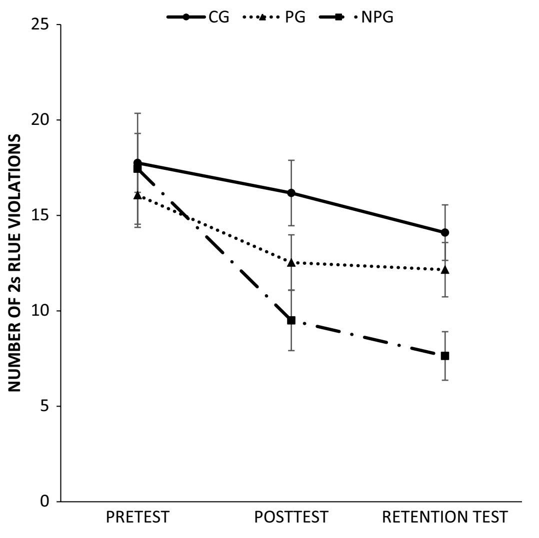

Figure 3. Mean number of 2-s rule violations for each group across the test phases. Error bars represent *SE*. CG = control group; NPG = nonpermissive group; PG = permissive emphasis group.

For the interaction between learning effect and time emphasis effect, the following pairs were significantly different ($p < .05$): NPG pretest ($M = 17.44$, $SD = 11.06$) versus NPG posttest ($M = 9.50$, $SD = 8.38$), NPG pretest versus NPG retention test ($M = 7.64$, $SD = 6.68$), and CG postest ($M = 16.18$, $SD = 10.84$) versus NPG posttest. There was a trend toward a significant difference ($p = .058$) between CG retention test ($M = 14.10$, $SD = 9.20$) and NPG retention test.

Fixation Times

An ANOVA on the mean percentage of fixation time (see Figure 4) for the HUT showed a significant learning effect, $F(2, 210) = 14.12$, $MSE = 0.21$, $p < .0001$, a significant time emphasis effect, $F(2, 105) = 8.35$, $MSE = 0.48$, $p < .001$, and an interaction between the two that was close to the classic significance threshold, $F(4, 210) = 2.24$, $MSE = 0.033$, $p = .064$. Tukey's HSD post hoc analyses were conducted.

For the learning effect, the followings pairs were significantly different ($p < .05$): pretest

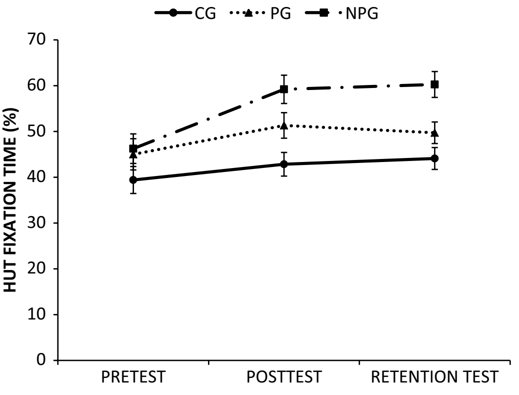

Figure 4. Mean percentage of time spent gazing at the head-up task (HUT) location for each group across the test phases. Error bars represent *SE*. CG = control group; NPG = nonpermissive group; PG = permissive emphasis group.

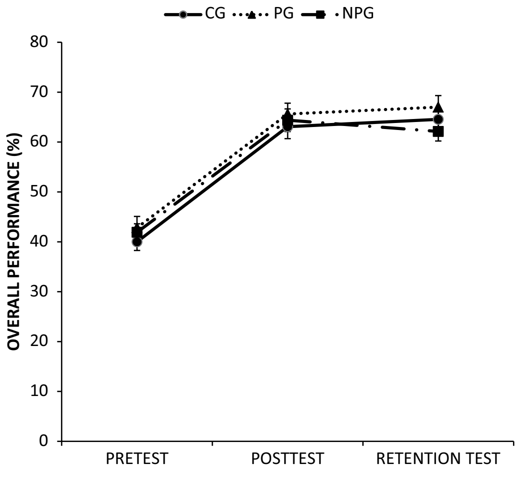

Figure 5. Mean overall performance of each group on pretest, posttest, and retention test. Error bars represent *SE*. CG = control group; NPG = nonpermissive group; PG = permissive emphasis group.

(*M* = 43.35, *SD* = 19.14) versus posttest (*M* = 50.81, *SD* = 18.16) and pretest versus retention test (*M* = 51.15, *SD* = 16.63).

For the time emphasis effect, the following pair was significantly different ($p < .05$): CG (*M* = 42.11, *SD* = 16.75) versus NPG (*M* = 55.24, *SD* = 19.26). There was a nonsignificant difference between PG (*M* = 48.69, *SD* = 16.37) and the other groups.

For the interaction between learning effect and time emphasis effect, the following pairs were significantly different ($p < .05$): NPG pretest (*M* = 45.80, *SD* = 19.46) versus NPG posttest (*M* = 59.26, *SD* = 18.82), NPG pretest versus NPG retention test (*M* = 60.39, *SD* = 17.23), CG postest (*M* = 42.84, *SD* = 16.36) versus NPG posttest, and CG retention test (*M* = 44.10, *SD* = 15.14) versus NPG retention test.

Overall Performance

The ANOVA on mean overall performances (see Figure 5) showed a significant learning effect, $F(2, 210) = 259.903$, $MSE = 18697$, $p < .00001$. Tukey's HSD post hoc analyses were conducted. The followings pairs were significantly different ($p < .05$): pretest (*M* = 41.47, *SD* = 11.18) versus posttest (*M* = 64.27, *SD* = 13.75) and pretest versus retention test (*M* = 64.47, *SD* = 12.93).

There was no time emphasis effect (CG: *M* = 55.88, *SD* = 17.53; PG: *M* = 58.49, *SD* = 14.70; NPG: *M* = 56.14, *SD* = 14.02), $F(2, 105) < 1$, $MSE = 210$, $p = .54$, and no significant interaction between the two, $F(4, 210) = 0.875$, $MSE = 63$, $p = .48$.

HDT Performances

The ANOVA on mean HDT performances (see Figure 6) showed a significant learning effect, $F(2, 210) = 202.41$, $MSE = 24103$, $p < .000001$. Tukey's HSD post hoc analyses were conducted. The following pairs were significantly different ($p < .05$): pretest (*M* = 35.08, *SD* = 13.15) versus posttest (*M* = 59.93, *SD* = 19.32) and pretest versus retention test (*M* = 61.91, *SD* = 18.87).

There was no time emphasis effect (CG: *M* = 52.10, *SD* = 21.35; PG: *M* = 54.29, *SD* = 21.54; NPG: *M* = 50.77, *SD* = 20.71), $F(2, 105) < 1$, $MSE = 319.5$, $p = .62$, and no significant interaction between the two, $F(4, 210) = 1.42$, $MSE = 170.1$, $p = .22$.

HUT Performances

The ANOVA on the mean percentages of correct answers in the HUT (see Figure 7) showed

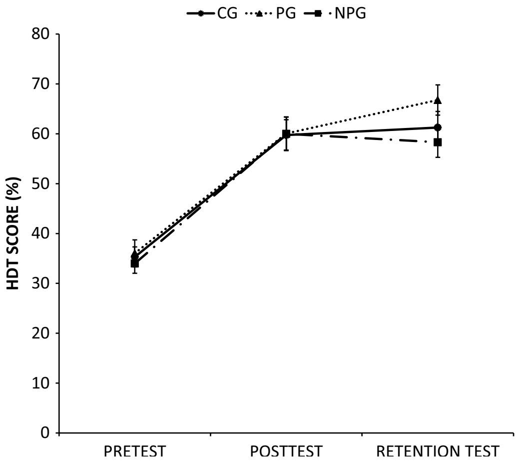

Figure 6. Mean head-down task (HDT) performances of each group on pretest, posttest, and retention test. Error bars represent *SE*. CG = control group; NPG = nonpermissive group; PG = permissive emphasis group.

a learning effect, $F(2, 210) = 86.417$, $MSE = 14156$, $p < .0001$. Tukey's HSD post hoc analyses were conducted. The following pairs were significantly different ($p < .05$): pretest ($M = 47.87$, $SD = 19.07$) versus posttest ($M = 68.61$, $SD = 16.56$) and pretest versus retention test ($M = 67.04$, $SE = 14.69$).

There was no time emphasis effect (CG: $M = 59.66$, $SD = 20.58$; PG: $M = 62.68$, $SD = 19.86$; NPG: $M = 61.51$, $SD = 17.22$), $F(2, 105) < 1$, $MSE = 252$, $p = .62$, and no significant interaction between the two, $F(4, 210) < 1$, $MSE = 152$, $p = .45$.

DISCUSSION

The objective of the present study was to test a training method intended to prevent unsafe aeronautical behavior (i.e., too much gazing time inside the cockpit) induced by modern cockpits. The present study also examined whether this method potentially hindered the learning of two simultaneous tasks. The training method consisted in learning a specific interval of time, emphasized by real-time notification warning participants that they were spending too much time gazing inside. Real-time emphasis was tested with an inside cockpit task (HDT) that had to be performed simultaneously with a see-and-avoid outside cockpit task (HUT). To

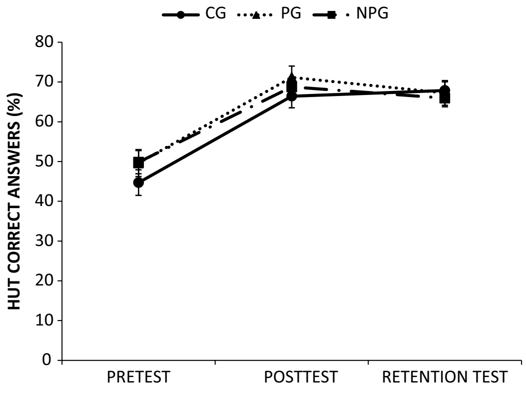

Figure 7. Mean percentage of correct answers to head-up task (HUT) for each group across the testing phases. Error bars represent *SE*. CG = control group; NPG = nonpermissive group; PG = permissive emphasis group.

test the efficiency of real-time emphasis, we had to objectify the possibility of individuals acquiring TIE, a skill that would allow them to respect the 2-s rule prescribed by aeronautical authorities and, at the same time, increase the amount of time that they spent gazing outside (Dubois et al., 2015). For each group, the test sessions (pretest, posttest, retention test) were conducted without 2-s rule emphasis.

Only NPG exhibited a significantly lower number of 2-s rule violations in comparison with CG and a significant decrease in 2-s rule violations after the training sessions. We failed to show any effect of permissive emphasis. During two concurrent visuospatial motor tasks (Wickens, 2002), visually emphasizing a time interval that forced participants to stop managing a task appeared to be a relevant means of learning this time interval in our dual-task situation. These results are in line with those of Taatgen et al. (2007), who showed that time interval can be learned in a dynamic dual-task visuoverbal-motor situation. One unexpected result was the absence of any significant difference between PG and CG on the posttest and 24 hr after the training sessions. With nonpermissive emphasis, participants were forced to stop managing the HDT after exactly 2 s, allowing us to surmise that the integration of a time interval is more effective when participants are forced to respect it. One possible explanation for this result is that nonpermissive emphasis directed more attentional resources to the time interval and enhanced integration. Another possible explanation is that because PG participants could pursue the HDT if they wished, they may have heeded the 2-s rule less during the training sessions and thus had less practice implementing it. By the same token, NPG participants presumably benefited from having to respect the time interval more and were thus able to achieve a higher level of automatization (e.g., Logan, 1988).

The purpose of teaching the 2-s rule during in-flight instruction is to ensure that more fixation time is allocated to the see-and-avoid task. In this study, the HDT was spontaneously more attractive to participants than the HUT, as evidenced by the mean percentage of time they spent fixating the HUT location (about 43% for all three groups before the training sessions). Data showed that NPG spent more time gazing at the HUT than CG did after the training sessions, thereby demonstrating the relevance of the real-time emphasis. These results are in line with those of Dubois et al. (2015), who studied gazing activity during a simulated flight. Although the 2-s rule still allowed participants to perform longer gazing at the HDT than at the HUT, our results showed that when they adhered to the 2-s rule, participants spent more time gazing at the HUT on average. What is the mechanism behind the transition from respecting the 2-s rule to spending more time gazing at the HUT? In the study by Dubois et al., air crew students had specific aeronautical knowledge, with 37 mean flying hours while performing functions on board. We can assume that their specific aeronautical knowledge, associated with meaningful simulated scenes (same instrumentation and virtual outside world), led them to direct their gazing activity at the outside world, in accordance with the aeronautical prescriptions that they had learned. By contrast, the participants in our study were university students with no prior aeronautical knowledge, and the scene had no particular meaning for them. The results of Dubois et al., combined with those of the present study, nonetheless suggest that participants' prior knowledge and the meaningfulness of the scene may not be entirely responsible for increased HUT fixation time. The mechanisms involved may therefore be more generic.

Concerning task performances, as participants performed both tasks, there were learning effects for the HUT and HDT. These results ruled out the issue regarding the potential dissociation of foveal gaze allocation and visual attention (Duchowski, 2007; Posner, 1980). We found no impact of either type of emphasis on task performance. We had expected to observe better performances on the HUT for the group that allocated more fixation time to the HUT. By the same token, lower HDT performances had been expected for the group that spent less time fixating the HDT. One possible explanation is that training was not sufficiently extensive to produce a significant difference in HUT and HDT performances across the groups. Another possible explanation is that differences in fixation times across groups after the training phase were not large enough to produce a significant modification in task performances.

Taken together, these results suggest that this training is a relevant means of adjusting gaze patterns across a head-down and head-up display, without hindering performances. One possible explanation is that emphasis allows an interval timing component to be incorporated into an intertasks coordination process. We propose naming this mechanism *time-based intertask coordination*.

Future studies should use the transfer method (e.g., Green, Strobach, & Schubert, 2014) to assess the generic/specific nature of the mechanisms responsible for time interval integration in a multitask situation. It is essential to understand their nature, if this training method is to be implemented in a simulated ecological environment. Simulation studies demonstrated the efficiency of flight simulation training (Jacobs, Prince, Hays, & Salas, 1990; Orlansky & String, 1977; Pfeiffer & Horey, 1987; Rantanen & Talleur, 2005). Simulators can thus be used to acquire absorption resistance skills, as requested by the aeronautical authorities. Moreover, the training can be adapted to individual gazing strategies and permit differentiated instruction, targeting individual characteristics.

Applications concern all individuals and transportation modes. For example, smartphones are widely used to assist car navigation, and they lead to attentional absorption issues. An application based on facial/eye recognition could be used to switch off the screen as soon as the driver exceeded a gazing time limit. This kind of software could be implemented to optimize human-machine interaction in intelligent vehicle systems.

To conclude, our findings will help to resolve the challenge of monitoring/assisting operators in real time during complex and dynamic operations to foster appropriate behavior, with the use of time emphasis to adapt the operators' attention-switching patterns to different situations.

KEY POINTS

- Major aeronautical human factors research challenges include (a) performing several tasks simultaneously and (b) ergonomic environment under constant change.
- Performing several tasks simultaneously requires specific gazing patterns to prevent unsafe aeronautical behavior (i.e. too much time spent gazing inside the cockpit).
- Time emphasis training appears to be efficient, with retention up to 24 hours after, while preserving task performance.
- The best time-interval acquisition was observed in a non-permissive emphasis.
- Most areas where absorption resistance is a major concern could benefit from this type of training to manage multitask situations.

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