Divided attention and visual anticipation in natural aviation scenes: The evaluation of pilot’s experience

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Abstract

The present study aims to investigate whether spatial representation bias can be used to assess the trainee’s air skills. Spatial representations contribute in large part to the development of situational awareness (Endsley, 1996), making it a key factor in aviation performance and safety. Blättler et al (2011) have shown that a memory displacement of spatial representation is larger among pilots than novices. The purpose of this study was to provide evidence that spatial representation bias can discriminate novice from experienced pilots. Furthermore, several studies showed that not all the processes underlying displacement are automatic (Hayes & Freyd, 2002). The second objective of this study was to test whether experts share the same sensitivity to divided attention as novices in a task measuring displacement, since the expert’s automation makes processes specific to his activities more resistant to the effect of the dual task (Froger, Blättler, Dubois, Camachon, & Bonnardel, 2018; Strobach, Frensch & Schubert, 2008). This study was conducted to explore these questions in an experiment with 19 experienced glider pilots from the French Air Force and 25 novices. Participants were shown dynamic real-world landing scenes in ego-motion (Thornton & Hayes, 2004) during a representational momentum (RM) task. Gaze fixations data were also recorded to explore their potential relationship with spatial memory bias. This study provides evidence that spatial representation bias can discriminate novices from experienced pilots who only have a few hours of training.

Introduction

Spatial representation is crucial when flying an aircraft. Situational awareness, which includes anticipation and is based on spatial representation, is a key element of air safety. However, it is difficult to objectively evaluate the evolution of performance in spatial representation during student training. The objective of this study was to test whether a process underlying spatial representation was sensitive enough to be an appropriate measurement and analysis tool. The experiment performed here evaluated the spatial representation of natural glider landing scenes by experienced pilots and novices.

Understanding spatial representation is a major challenge since it is the result of the influence of multiple factors. Its understanding is essential for actors in the aeronautics world (industries, training schools, etc.) to design both human-system interaction interfaces and ad hoc training. It must de facto be studied through a rigorous protocol. A special case for studying spatial representation is that of the processes that underlie "Representational Momentum" (RM) (Freyd & Finke, 1984). Because of its properties, described below, this work is part of understanding how the cognitive system succeeds in learning to cope with complex dynamic visual situations. Representational momentum refers to a memory displacement for the final position of a previously viewed moving target in the direction of the target’s motion. Finke, Freyd and Shyi (1986) suggested that the properties of such a memory displacement could help observers anticipate the future positions of moving objects. In the rest of the article, the term "displacement" will be used to refer to a displacement of the spatial position in memory of a moving object or scene.

The variables that influence the direction and amplitude of displacement act in a similar way to the physical principles of movement. That is why studying displacement is a way of studying how the physical principles of movement are incorporated into mental representations. One of the experimental protocols (figure 1) conventionally used to show a displacement is that of Hubbard and Bharucha (1988). The authors presented participants with a target that moved continuously and linearly (to the left or right and up or down). After a few moments of animation, the target disappeared unexpectedly. As soon as the target disappeared, participants clicked on the place where they thought the target had disappeared. The results showed that participants recalled the position of the target, at the time of its disappearance, not at its exact location, but a little further in the direction of the target's trajectory. They suggested that, like a moving object that does not immediately stop but continues along its path under its own momentum, spatial representation does the same and shifts the last perceived spatial position in the direction of the motion.

![Figure 1. Material and results adapted from Hubbard & Bharucha (1988)](image-url)
The distance between the actual disappearance position and the one recalled by the participants can vary in magnitude depending, for example, on the speed of a target's movement. The higher the speed, the greater the magnitude of the displacement (Freyd & Finke, 1985; Hubbard & Bharucha, 1988; de sá Teixeira, Hecht, & Oliveira, 2013). The analogies between physical motion and displacement are also spatio-temporal in nature. Freyd and Johnson (1987) varied the time between the disappearance of a moving target and the latency with which the participant gave his response (from 10ms to 900ms). The results obtained showed an increase in displacement magnitude with the increase in encoding latency. This corresponds to what would happen physically, as the movement of an object lasts for a few moments if nothing prevents it. But it should be noted that when latency exceeded a certain threshold, in this case 300 ms, this effect decreased as latency increased. This decrease after 300 ms suggests that the evolution of the displacement is similar to the movement that an object would actually have, namely stopping of movement over time. This similarity between real movement and displacement makes the latter a dynamic representation. Taken together, these results suggest that displacement is based on a spatio-temporal coherence similar to that of physical principles. Overall, displacement is described in terms of dynamic representations and thus, by analogy to real-world dynamics, Hubbard (2010) conventionalized it as the “momentum metaphor”, suggesting as said earlier that the principles of momentum are indeed incorporated into mental representation.

The plurality of analogies from the physical world has motivated the prolific development of research protocols and since the 1980s, a significant number of variables that modulate displacement have been investigated (see Hubbard, 2005b, 2018 for reviews). While some variables foster the development of a displacement in the direction of perceived movement e.g., speed (Freyd & Finke, 1985; Hubbard & Bharucha, 1988; de sá Teixeira, Hecht, & Oliveira, 2013), downward motion (Hubbard, 1990; Hubbard & Bharucha, 1988), and high contrast (Hubbard & Ruppel, 2014), others foster a displacement in another direction e.g., representational gravity (de sá Teixeira, 2014; de sá Teixeira & Hecht, 2014; Hubbard, 1995b, 2005b; Motes, Hubbard, Courtney, & Rypma, 2008), reduce the magnitude of the displacement e.g., representational friction (Hubbard, 1995a, 1995b), or promote a displacement in the opposite direction of movement e.g., surrounding context (Hubbard, 1993), and memory averaging (see for example Hubbard, 1996). Thus, outside the laboratory, there is a set of different variables, with diverse, congruent or opposite influences, which are co-articulated and induce a result which is the spatial representation of a scene. For example, Hubbard and Bharucha (1988) showed that the position of a target moving in a straight line is recalled further in the direction of movement but also lower. Many replicates (Hubbard, 1990, 1995b, 1997, 2001) have determined that this result of a combination of a forward displacement effect and the effect of implicit knowledge of gravity (representational gravity) results in a downward displacement. In this vein, Hubbard (1995a; 2010) proposed a model that reflects this multiplicity of influences. In his ”vector addition” model, each type of influence is matched by a vector that codes for the direction and magnitude of displacement. “Such vectors can be broadly construed as corresponding to magnitudes and directions of activation within a network architecture that preserve functional mapping between physical space and represented space” (Hubbard, 2010, p. 352). While many studies have
massively contributed to determining low-level influences (target shape, surrounding context, etc.), more recent studies show that displacement is also modulated by cognitive factors such as the expertise of observers and the allocation of attention resources.

Blättler, Ferrari, Didierjean and Marmèche (2011) showed an effect of expertise on displacement in the aeronautical context. In their study the authors adjusted the Thornton and Hayes (2004) protocol. Dynamic simulated aircraft landing scenes were presented to participants who were either total novices to aeronautics or expert pilots (over 3000 hours of flight experience). The scenes were interrupted by the display of a black screen lasting 125 ms and then resumed in one of three conditions: a shift forward (with respect to the aircraft’s direction of motion), a shift backward (in the direction opposite to the plane’s motion), or no shift (i.e., at exactly the same point as before the interruption: the same-resumption condition). In the shift conditions, the size of the forward and backward shifts was manipulated (125 ms, 250 ms, 375 ms, and 500 ms). Participants had to compare the last image seen before the cut to the first image seen after the cut and decide whether the scene had shifted backward or forward. The results showed that only the expert pilots produced a forward displacement, while among the novices no displacement (either forward or backward) was obtained. After successive studies increasing the accuracy of the measurement, a significant displacement was obtained in the novices. The magnitude of the displacement was so short in the novices that it could not be observed with the accuracy measurement used to detect a displacement among the experts in the first study. This expertise effect resulted in an increase in the amplitude of the displacement in the direction of the perceived movement.

Similar results have been obtained in the automobile context (Blättler et al., 2010; Blättler et al., 2012, 2013; Didierjean, Ferrari & Blättler, 2014) and in the sports context (Hiroki, Mori, Ikudome, Unenaka, & Imanaka, 2014; Jin et al., 2017; Chen, Belleri, Cesari, 2019; Gorman, 2015; Anderson, Gottwald, & Lawrence, 2019). Thus, the effect of expertise seems robust. However, the way in which expertise is manifested is not clearly established. Furthermore, the literature (see for review Gegentfurtn, Lehtinen & Säljö, 2011; Peißl, Wickens & Baruah, 2018; Reingold, Charness, Pomplun & Stampe, 2001; Ziv, 2016) show that systematic eye movement differences between experts and novices occur. Therefore, in accordance with the first objective of the current study, eye tracking data were collected, as part of an exploratory attempt to gain insight into the manifestation of the experience in the displacement.

Another way in which the effect of expertise could manifest itself in the processes underlying the displacement is through the effect of automation of cognitive procedures. Hayes and Freyd (2002) showed that not all the processes underlying displacement are automatic (see also, Joordens, Spalek, Ramzy & Duijn, 2004). However, since the constitutive process of expertise development is automation (Logan, 1988), it is conceivable that the processes underlying the displacement if it shares the same property may gradually become automatic. Thus, the more experienced an individual is, the more automated specific processes of his activity are. This automation makes it more resistant to the effect of the dual task (Froger, Blättler,
Dubois, Camachon, & Bonnardel, 2018; Strobach, Frensch & Schubert, 2008). Experiments on divided attention (Hayes & Freyd, 2002; Joordens et al., 2004) show an increase in the amplitude of forward displacement when attention is divided during perception of the moving target. If the processes underlying displacement share the same properties as those associated with automation, the displacement of experienced individuals should be less sensitive to the dual task effect than that of novices. The second aim of this study was therefore to test whether experts share the same sensitivity to divided attention as novices in a task measuring displacement.

In summary, the first purpose of this experiment was to determine whether displacement can be an index that would be sensitive enough to assess the progress of student pilots. The assumption is that experienced pilots will produce a greater displacement in the direction of movement than novices. Complementary to this goal, the eye tracking was used to explore the link between this displacement and gaze fixations of the experienced pilots. The second objective was to evaluate whether the processes underlying the displacement are sensitive to the automation process conventionally observed during the development of expertise. The hypothesis is that experienced pilots will be less sensitive than novices to a disturbance caused by a dual task.

Method

Participants

Forty-four participants were recruited for the study, drawn from two distinct skill levels: an experienced glider pilot group (n = 19) with 78.16 flying hours on average (SD = 177) and an average age of 23 years (SD = 5), and a second experimental group (n = 25) composed entirely of novices (M_age = 27 years, SD = 8). All participants were volunteers, had normal or corrected vision and were naive to the specific purpose of the study.

Material

Following Blättler et al. (2011), 10 video sequences (figure 2) inside a Centrair Marianne C201B glider were used (24 frames/s). Each landing scene was filmed from the pilot’s perspective (i.e., first-person view, with a small part of the cockpit visible and no view of the instruments). To ensure that the inclination, angle and approach speed were the same for all scenes or to ensure that all approaches were consistent compared to an optimal approach, an instructor was present on all flights.

Figure 2. Scene example with, the left to the right: -250 ms, 0 ms and +250 ms condition.
The speed chosen for the landing was a standard speed for a glider (i.e., the distance a glider travels in 125 ms is about 3.125 meters at a speed of 90 km/h - 87.1 km/h without wind for an optimal run). The test stimuli were displayed on a Dell Precision 7710 laptop computer (17.3 in. screen, refreshment 60 Hz, resolution 1920 x 1080). The participants were positioned 60 cm from the screen. Each scene (all of which had a different landing scenario) was used to make nine videos. Each of these nine videos was followed by a perceptual interruption (interstimulus interval, ISI) lasting 250 ms. After the cut, the trial resumed in one of nine conditions (Figure 3) that differed in the magnitude of the shift of the image (-250 ms, -187 ms, -125 ms, -62 ms, 0 ms, +62 ms, +125 ms, +187 ms, +250 ms). There was a total of 90 different videos (10 scenes x 9 shifts = 90).

![Figure 3: Landing scene and conditions in accordance with Blättler et al., (2011).](image)

Eye position data were captured by an eye-tracker Tobii Pro X3 with a sampling rate of 120 Hz. The analyses used to examine the data were based on static exploratory areas to collect information on participants' eye movements and fixations.

**Procedure**

Each trial (i.e., video stimuli) was displayed on the computer monitor for 3 seconds, followed by the 250 ms ISI. After the perceptual interruption, the trial was resumed with an image from one of the nine conditions. In the same-resumption condition (i.e., “no shift condition”), the video started up at exactly the same point as before the cut (a comparison between the two images shows that they are identical).

In the forward-shift condition, the trial started after a forward shift of +62 ms, +125 ms, +187 ms, or +250 ms. In the backward-shift condition, the trial resumed with an image corresponding to -62 ms, -125 ms, -187 ms, or -250 ms. From the moment the test started (i.e., when the image appeared) the participant had 15 seconds to respond. If he answered, or if the 15 seconds had elapsed, a black fixation cross on a white screen appeared for 2 seconds, followed by a new trial (Figure 4).
The experiment was conducted in two successive phases; a task familiarization phase, followed by the experimental phase. Before the familiarization phase, the experimenter gave the participants the following instructions.

**In the full attention condition:**
Participants had to compare the last image seen before the cut to the first image seen after the cut and decide whether the scene had shifted backward or forward. In line with previous studies, note that no information about the existence of same resumptions was given to the participants. Indeed, the PSE’s measure is showing the point of maximal uncertainty, in this particular design, if the possibility of same resumption is not introduced to the participants. That way participants must answer according to their representations and not according to their knowledge of possible answers. After reading the instructions, the participants became familiar with the task by completing 14 practice trials (7 in the divided attention condition, 7 in the full attention condition) on two scenes that were not used in the experimental phase. Then the experimental phase began. In this phase, 10 scenes were used, each giving nine resumption conditions. This made 90 trials (10 * 9), which were presented in a random order to all participants.
In the divided attention condition:
Participants performed the primary task as described in the first condition while simultaneously listening via headphones to an auditory recording of a continuous stream of four randomized individually presented digits during each landing scene. They were instructed to monitor this recording for the occurrence of even digits (2, 4, 6 and/or 8), and to mentally keep track of the number of times that such runs had occurred to recall it. It should be noted that the presentations of the one to four even digit runs were not linked to the visual presentation of stimuli in any systematic way. This test condition showed the same clips as those displayed in the full attention condition. The clips were presented in a random order.

Results
An analysis of RM magnitude was used to assess the magnitude of shifts and to compute the point of subjective equality (PSE) for each participant. This point is the theoretical value of the stimulus that the participant considers to be subjectively equal to the standard. It indicates the point of maximum uncertainty. This measure was computed by fitting the distributions of the percentages of each participant. Each PSE was calculated from this curve by taking all the responses of that participant into account. A positive PSE (i.e., significantly above zero) indicated a forward displacement (FD). A negative PSE (i.e., significantly below zero) indicated a backward displacement (BD) (see Figure 5 for the PSE mean by group).

Table 1. PSE descriptive data. Full attention condition (FA); Divided attention (DA).

<table>
<thead>
<tr>
<th>Descriptive</th>
<th>Novices FA</th>
<th>Novices DA</th>
<th>Pilots FA</th>
<th>Pilots DA</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>25</td>
<td>25</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Mean</td>
<td>-34.40</td>
<td>-59.36</td>
<td>-16.68</td>
<td>3.342</td>
</tr>
<tr>
<td>SD</td>
<td>52.62</td>
<td>77.05</td>
<td>44.28</td>
<td>72.03</td>
</tr>
</tbody>
</table>

An analysis of variance (ANOVA) was conducted with experience as a between-groups factor (novices vs experienced pilots) and attention as a within-group factor (full attention vs divided attention). The experience factor was significant, $F(1, 42) = 6.133$, $MSE = 34911$, $p < .05$. Novices’ mean PSE was significantly lower than that of the experienced glider pilots. The attention effect was not significant, $F(1, 42) = 0.056$, $MSE = 131.6$, $p > .1$. The interaction between experience and attention was significant, $F(1, 42) = 4.658$, $MSE = 10925.7$, $p < .05$.

Hence, subsequent t-test comparisons were made. The analyses showed that the means of experienced glider pilots in FA, $t(18) = -1.642$, $p = .118$ and DA, $t(18) = 0.202$, $p = .842$ were not significantly different from zero, while they were significantly different from zero for novices in both, FA, $t(24) = -3.269$, $p = .003$, and in DA, $t(24) = -3.852$, $p < .001$. Moreover, while there was no significant difference between FA and DA for experienced glider pilots, novices’ mean PSE in FA was significantly larger than the novices’ mean PSE in DA, $t(42) = 2.029$, $p = .027$. Hence, the pattern of the interaction in Figure 5 demonstrates that backward displacement was larger for novices in DA than in FA. Conversely, there were no backward displacement in DA or FA for experienced pilots. Therefore, the interaction shows that experience modulates the effect of attention allocation in the displacement process. Furthermore, in both FA and
DA, the experienced pilots’ mean PSE was significantly superior to the novices’ mean PSE, \( t(42)=1.795, p=.045 \) and \( t(42)=3.559, p=.001 \), respectively.

![Figure 5. PSE mean in Full Attention (FA) and Divided Attention (DA) for each experience group (Novice vs Experienced pilot).](image)

To assess the validity of the divided attention condition, the average success rate of participants in the dual task was measured. The average success rate of participants in the dual task was 93.55%. The mean success rate was 94.60% (SD =3.75) for the experienced glider pilots and 92.67% (SD=6.75) for the novices. The experienced pilot’s mean PSE was significantly inferior to one hundred, \( t(9)=4.557, p<.01 \). The novices’ success rate was also significantly inferior to one hundred, \( t(11)=-3.765, p<.01 \). The experienced pilots’ mean success rate was not significantly superior to the novices’ mean success rate, \( t(20)=-0.798, p =.223 \). The results did not show any ceiling effect.

**Eye fixation data**

Eye tracking data were recorded for twenty-two of the forty-four participants: 10 in the experienced glider pilot group with 125.8 flying hours on average (SD = 238) and an average age of 24 years (SD = 6.5), and 12 in the experimental group of novices (\( M_{age} = 27 \) years, SD = 6.5). We computed fixation duration in seconds on two main areas of interest; the upper part and the lower part of the screen.

Expert pilots (French air force instructors) on the one hand tend to describe their visual behaviour as having a tendency to look as far as possible along the runway or beyond when flying. Secondly, the instruction of students follows this rule which has been established on the basis of the experience of these same instructors. As no data were available, we decided to explore this subjectively recalled behaviour by separating the screen during the experiment into these two main areas. The software used and the eye tracking device made it possible to monitor the time of fixation of the gazes in these areas. Thus, the scenes were divided into two equal areas of interest, (1) the
The analyses were based on the average fixation duration in seconds. As a way to explore the link between information-gathering strategy and forward displacement it was decided to use correlation. Our assumptions include only experienced glider pilots because novices did not recall any flight experience, and therefore should not be affected by the type of gaze behaviour they employ.

Table 2. Eye fixations Descriptive data. Full attention condition (FA); Divided attention (DA).

<table>
<thead>
<tr>
<th>Descriptive data</th>
<th>Novices FA</th>
<th>Novices DA</th>
<th>Pilots FA</th>
<th>Pilots DA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper part of the screen (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>0.358</td>
<td>0.331</td>
<td>0.426</td>
<td>0.368</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>0.257</td>
<td>0.393</td>
<td>0.382</td>
<td>0.379</td>
</tr>
<tr>
<td>Lower part of the screen (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>1.504</td>
<td>1.53</td>
<td>1.658</td>
<td>1.743</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>0.416</td>
<td>0.456</td>
<td>0.496</td>
<td>0.487</td>
</tr>
</tbody>
</table>

Correlation analysis full attention (FA) trial block:

Experienced pilot’s fixation data for the upper part were positively correlated to PSE, $r_s = 0.697$, df=9, $p = .016$. Meaning that when pilots were looking at the upper part they recorded higher PSE score. Also, fixations on the upper part of the screen were positively correlated with the number of flying hours, $r = 0.568$, df = 9, $p = 0.043$. This measurement shows that pilots with the most flying experience were those who were looking at the upper part of the screen the most.

Experienced pilot’s fixation data for the lower part were negatively correlated to PSE, $r_s = -0.564$, df=9, $p = 0.048$. This indicates that when pilots were looking at the lower part they recorded lower PSE score. Also, fixations on the lower part of the screen were negatively correlated with the number of flying hours, $r=-0.576$, df=9, $p = 0.041$. This measure shows that pilots with less flying experience were those who were looking at the lower part of the screen the most.

Correlation analysis divided attention (DA) trial block:

No correlation in divided attention was reported, either among pilots or novices. No correlation between the number of flying hours and eye fixations was found.
Discussion

The displacement of the spatial representation of experienced pilots and novices, whose attention was divided, was evaluated for real dynamic scenes of glider landing. The first objective was to assess whether this protocol is sufficiently accurate to be used as a tool to assess the evolution of student pilots’ skills as well as to explore the relationship between experienced pilot’s visual features and the spatial memory bias. The second objective was to evaluate whether the processes underlying the displacement are sensitive to the automation process conventionally observed during the development of expertise.

Our findings are in line with the literature (Blättler et al., 2010; Blättler et al., 2012, 2013; Didierjean et al., 2014; Hiroki et al., 2014; Jin et al., 2017; Chen et al., 2019; Gorman, 2015; Anderson et al., 2019), indicating that there is an experience effect within the displacement process, here for natural dynamic glider landing scenes. It was found that novices have a significantly greater backward displacement than glider pilots even though, on average, the pilots only have 78 flight hours compare to 3000 hours for the expert participants of Blättler et al. (2011). These results are consistent with the possibility of using such a protocol to evaluate the evolution of student pilots’ skills during their training. However, the fact that no group has any forward displacement should put this interpretation into perspective. According to Hubbard's (2010) vector addition model, it can be concluded that the device used here includes a "backward" factor that influences all groups. Thus, future studies will have to determine what this influence is in order to control it.

The results obtained when attention is divided are in line with those of Gorman et al. (2018). Experienced pilots did not show sensitivity to the division of attention on displacement, while for novices the division of attention acted as a "backward" influence. It is currently impossible to conclude on the automation of the processes underlying spatial representation, but in this particular situation, it appears that there is an automation process that induces a reduction in the "backward" shift effect among experienced pilots, even if it is not yet highlighted. In these terms, the use of this dual-task method, which modulates the direction and amplitude of the displacement, is an additional tool for evaluating performance evolution of student pilots during their training.

The results obtained with gaze fixations present a link between gaze fixations and displacement in individuals who are familiar with the scene and are free to explore it visually when their attention is not divided. These results explore a gap between the research about the expert’s ocular behaviour and the expert’s anticipation, whereas Gorman's study (2018) suggests that differences in displacement of spatial representation are unlikely to be related to differences in visual behaviours. Second, these data show an effect of the division of attention among experienced pilots. This effect might point to a sensitivity of experienced pilots to the division of attention that can be mapped into measures other than displacement. Further studies exploring more directly the link between a particular position in the scene and spatial memory bias should be made before eye tracking data might be used as a complementary tool to evaluate the evolution of the performance of student pilots during their training.
In conclusion, this study contributes to a better understanding of spatial representation in aviation and of pilots’ visual interaction with a real-world environment. Our results have confirmed that trainees can be evaluated with the use of displacement measurement. Since gaze fixations also proved useful as a complementary index of pilots’ anticipatory behaviours and experience, the use of eye tracking technology in addition to other data recording might assist in the comprehension and application of better training for situational awareness. Finally, the use of this evaluation methodology is expected to be useful in reducing the cost of training. Indeed, it should provide a way to assess the efficiency of simulation training (by evaluating anticipation scores) especially during critical phases as in landing scenarios.

References


