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Representational Momentum in Aviation

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The purpose of this study was to examine the effects of expertise on motion anticipation. We conducted 2 experiments in which novices and expert pilots viewed simulated aircraft landing scenes. The scenes were interrupted by the display of a black screen and then started again after a forward or backward shift. The participant's task was to determine whether the moving scene had been shifted forward or backward. A forward misjudgment of the final position of the moving scene was interpreted as a representational momentum (RM) effect. Experiment 1 showed that an RM effect was detected only for experts. The lack of motion anticipation on the part of novices is a surprising result for the RM literature. It could be related to scene unfamiliarity, encoding time, or shift size. Experiment 2 was run with novices only. It was aimed at testing the potential impact of 2 factors on the RM effect: scene encoding time and shift size. As a whole, the results showed that encoding time and shift size are important factors in anticipation processes in realistic dynamic situations.

Keywords: representational momentum, expertise, visual anticipation

In everyday situations, people must continuously interact with dynamic environments that are constantly changing. Very often, information intake is interrupted for reasons related to the observer (e.g., blinking) or to outside events (e.g., windshield wiper movement during automobile driving). When the perception of the environment is interrupted, even very briefly, the cognitive system must be able to fill in the perceptual gap between the last image actually perceived and the new image seen. One of the most powerful adaptive mechanisms available to the visuocognitive system for avoiding localization errors is to anticipate the probable evolution of the dynamic event as the environmental scenes are being perceived (see Clarke, Ward, & Jones, 1998; Gray, 2005; Gray & Regan, 1999). An important question that arises is whether such highly adaptive mechanisms (see Munger, Owens, & Conway, 2005) take effect in a similar way in all individuals, or whether they are modulated by the knowledge the observer has of the scenes perceived. One way of studying anticipation processes and their development with experience consists of comparing the performance of novices and experts in a given knowledge domain. Many studies on expertise have shown that the perception of experts (in their domain of expertise) evolves over time. The knowledge acquired by experts is known to have an impact on many aspects of perception, including the anticipation of how a situation will evolve (Didierjean & Marmèche, 2005; Ferrari, Didierjean, & Marmèche, 2006; Gobet & Simon, 1996). The domain studied in this article was visual scenes of aircraft landings from the pilot's point of view. Using this domain made it possible to compare novices, who had never been confronted with this type of visual scene, and experts, who were very skilled at analyzing such scenes, namely experienced pilots from the French Air Force.

The paradigm implemented in the present study was the *representational momentum* (RM) paradigm (for a review, see Hubbard, 2005, 2006; Kerzel, 2006). RM refers to the tendency of observers to "remember" the stopping point of an event as being farther along in the direction of motion than it is in reality. In the seminal study by Freyd and Finke (1984), a rotation movement was implied by presenting a rectangle in three different orientations in succession. Then a fourth rectangle was shown that was either in exactly the same position as the third rectangle or tilted in the same or opposite direction to that of the implied motion. The participants' task was to decide whether the fourth rectangle was in the same position as the third one. The results showed that participants had more trouble rejecting the rectangles whose orientation extended the implied motion than those indicating a backward movement. These findings were interpreted as a sign of *forward displacement* (FD), relative to the last rectangle presented, of the position stored in memory.

Most studies using this paradigm have worked with very simple dynamic visual scenes that require participants only to analyze a moving target. Few studies have dealt with complex dynamic scenes, and among them, not many have looked at effects of expertise in a specific domain requiring years of training. Here, we

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attempted to find out whether piloting expertise modifies the RM effect when the dynamic visual scenes are videos of an aircraft preparing to land on a runway.

Since the original work by Freyd and Finke (1984), a large body of research on RM has shown that when the cognitive system is processing a dynamic scene, it has the ability to extrapolate the probable evolution of the current scene. Most of the research has dealt with the role played by the properties of a moving object in the FD, and to a lesser extent, with how this effect is modulated by the perceiver's knowledge of the object. Some studies have shown that RM depends on the moving target's physical characteristics, including its shape (Kelly & Freyd, 1987; Nagaï & Yagi, 2001), direction (Halpern & Kelly, 1993; Hubbard, 1990; Munger, Solberg, Horrocks, & Preston, 1999), speed (Freyd & Finke, 1985), and acceleration (Finke, Freyd, & Shyi, 1986), and also by whether the target is moving away from or coming toward the participant (Hayes, Sacher, Thornton, Sereno, & Freyd, 1996; Hubbard, 1996). All of these properties can act as cues to where the object is likely to be located in the future. The FD has been demonstrated using a wide variety of materials, including both dynamic stimuli (e.g., a moving dot, a rotating rectangle, continuous motion of a set of dots; for a detailed review, see Hubbard, 2005) and static stimuli such as drawings or still photographs of actions (Freyd, 1983; Freyd, Pantzer, & Cheng, 1988). One of the conclusions drawn in all of these studies is that "frozen" actions are usually perceived in terms of their dynamic dimension. Other studies, although scarce, have addressed RM by examining the effects of the observer's prior implicit knowledge, including principles of physics such as gravity (Hubbard, 1995, 1997; Hubbard & Bharucha, 1988) and friction (Bertamini, 1993). As a whole, these studies showed that FD is generated in many situations, but that this effect can be modulated by both the physical characteristics of the moving object and the observer's knowledge of the scenes.

In line with the above research, our study was based on two important considerations. First, most studies on FD have presented relatively simple dynamic stimuli (rotating rectangles, sets of dots, a small number of items that are not action-related, etc.); few have used moving scenes. The study by Thornton and Hayes (2004) is one of the rare studies that used dynamic scenes (see also DeLucia & Maldia, 2006; Munger et al., 2005). Thornton and Hayes had participants view videos showing a synthesized image of a road as seen from inside a car driving at 55, 65, or 72 km/hr. The videos were temporarily interrupted by a black screen lasting 250 ms. After the interruption, the film continued and the participants had to decide whether the scene resumed at exactly the same point as it had stopped (same-resumption condition) or at some other point. When the scene resumed at a different point, it could be either with a shift forward or with a shift backward. The results showed that forward shifts were more difficult to reject than backward shifts, and that the point judged as the most acceptable resumption point was shifted by about 1 m in the car's direction of motion. This study thus demonstrated that FD can also be found in the case of dynamic scenes. The study we report here was aimed at extending this finding to other types of dynamic scenes.

Second, very few researchers have looked into the potential effects of experts' domain-specific knowledge on RM phenomena. In an earlier study (Blättler, Ferrari, Didierjean, van Elslande, & Marmèche, 2010), we adapted the Thornton and Hayes (2004) paradigm while varying the expertise level of the participants: They were either experienced automobile drivers or inexperienced automobile drivers (people without a driver's licence). The results indicated that although all participants of both expertise levels exhibited FD, experienced drivers had a larger FD than inexperienced ones. Knowledge acquired from years of driving modulated FD on driving-scene judgments.

The first goal of the study reported here was to show that FD is modulated by the observer's level of expertise in piloting. This finding would allow us to contend that FD modulation by domain-specific expertise can be generalized to other domains. Then, the second goal of the present study was to find out whether FD would be observed for "true" novices, or whether this effect requires some minimal amount of knowledge of the scenes observed. One of the limitations of the Blättler et al. (2010) study was that the inexperienced drivers were not "true" novices. As car passengers, the novices must have seen the same types of visual scenes as the experienced drivers. Indeed, Jordan and Hunsinger (2008) argued that even riding in an automobile can modify the person's perception of the driving situations he/she observes. This question is important at a more general level because, although RM is a particularly robust phenomenon (Courtney & Hubbard, 2008; Ruppel, Fleming, & Hubbard, 2009) that has been observed in many different situations, in the vast majority of studies, the observers were not actually real novices relative to the scenes presented.

Experiment 1

In Experiment 1, we predicted that there would be larger FD among expert pilots than among novices (participants with no aircraft piloting experience). The FD of each group was measured using moving scenes of an airplane landing, seen from the pilot's point of view. 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: 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. If it is true that expert pilots anticipate more than novices do in their knowledge domain, then in the same-resumption condition, the experts should give significantly more "backward" responses than the novices. In the shifted conditions, if participants anticipate, they should have more trouble seeing forward shifts than backward shifts. This difficulty should be greater for experts than for novices.

Method

Participants. Thirty-six participants divided into two groups took part in the experiment. Group 1 was made up of 21 novice participants (mean age = 31 years, *SD* = 5), who had never been in the cockpit of an airplane or on board an aircraft simulator. Group 2 was made up of 15 experts pilots from the French Air Force (mean age = 38.5 years, *SD* = 6.5; mean number of flying hours = 3,193, *SD* = 1,488). All participants had normal or corrected-to-normal eyesight and were unaware of the goals of the experiment.

Materials. The open-source flight simulator called FlightGear was used to obtain the scenes (24 frames/s). Eighteen different landing scenes were generated (i.e., each with a different background). The landing was seen from the pilot's point of view (first-person view), with no part of the airplane visible (cockpit, airborne instruments, etc.). To ensure that the slope, angle, and speed of approach were the same in all 18 scenes, the landing scenes were generated with the help of an autopilot input into the FlightGear software. Two expert pilots (who did not participate in the experiment and had 4,000 hr and 3,500 hr of flying experience, respectively) agreed that all of the scenes were realistic but unrecognizable.

The speed chosen for the landing was a standard speed for a military jet fighter (i.e., the distance the aircraft travels during 125 ms is about 7 m at a speed of 200 km/h). The video montage at different resumption times was achieved using Pinnacle Studio Plus Version 10 software. The experiment was run on a Dell Latitude 120L laptop computer (laptop 15.4 in., refreshment 61 Hz; resolution 1,024 × 768). Participants were placed 60 cm from the screen. Each initial scene (i.e., with its particular background) was used to make nine videos that differed only in the magnitude of the shift after the cut (–500 ms, –375 ms, –250 ms, –125 ms, 0 ms, +125 ms, +250 ms, +375 ms, +500 ms). To avoid any confusion between the shift distances (initially measured in milliseconds) and the duration of the cut (measured in milliseconds), shift distances were converted into number of images (e.g., given that 1 s = 24 frames, 125 ms = 3 frames). Thus, shift distances became –2 frames, –9 frames, –6 frames, –3 frames, 0 frame, +3 frames, +6 frames, +9 frames, +12 frames. A scene presented with a shift of +3 frames, for example, meant that when the video resumed, three images had been removed from the moving scene. This gave us 162 videos in all (18 × 9 = 162).

An example of the scenes presented in the three conditions is given in Figure 1: same resumption (0 frame), forward shift of 12 frames, and backward shift of 12 frames.

Procedure. After 3 s on each trial (i.e., each video), a black screen lasting 125 ms (interstimulus interval or ISI) was displayed. After the cut, the trial resumed in one of nine conditions. In the same-resumption condition, the video started up at exactly the same point as before the cut (the comparison frame and the first image after the cut were identical). In the forward-shift conditions, the trial started after a forward shift of 3 frames, 6 frames, 9 frames, or 12 frames (the size of the first shift corresponds to the ISI duration, 125 ms = 3 frames at 24 frames/s).[1] In the backward-shift conditions, the trial resumed with an image corresponding to 3 frames, 6 frames, 9 frames, or 12 frames before the cut. Once the video had resumed, the trial continued until the aircraft touched the runway (15 s after the black screen disappeared) or as soon as the participant responded. After the participant responded, an intertrial screen asked the participant to tap a key to start the next trial.

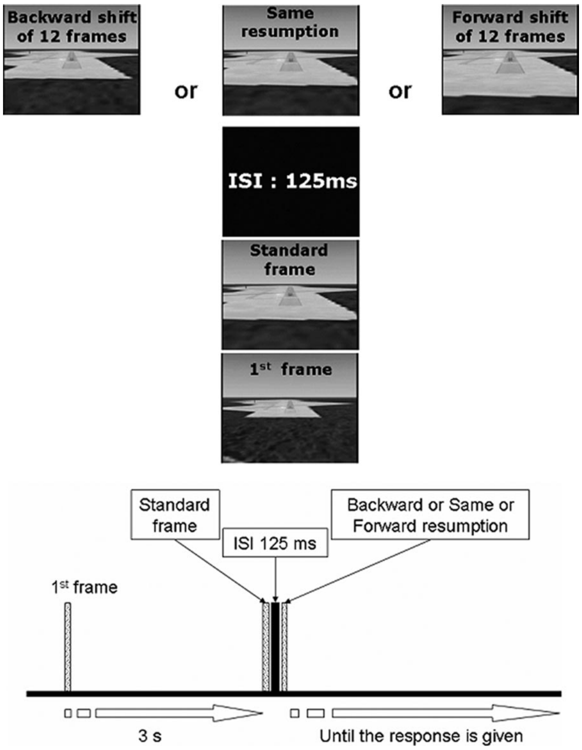

Figure 1. Material (top) and procedure (bottom) of Experiment 1. The video began with 3 s of a landing scene. Then a cut occurred with an interstimulus interval (ISI) of 125 ms. After the cut, the video resumed with a backward shift (upper left: backward shift of 12 frames), no shift (upper middle), or a forward shift (upper right: forward shift of 12 frames).

The experiment had two phases: a task familiarization phase, followed by the experimental phase. Before the familiarization phase, the experimenter gave the participants the following instructions to read: "You are going to see some videos simulating the landing of an airplane from the pilot's point of view. After a few seconds, the video will be interrupted for a short while. Then the video will resume either with a forward shift (as if time had abruptly jumped forward), or with a backward shift (as if time had abruptly jumped backwards). Your task will be to decide whether the video resumed after a forward shift or a backward shift, and to respond by pressing the blue key to answer 'forward shift' or the red key to answer 'backward shift.'" Note that no information about the existence of same resumptions was given to the participants at this point. After reading the instructions, the participants became familiar with the task by doing 18 practice trials on two scenes that were not used in the experimental phase. Then the experimental phase began. In this phase, 16 scenes were used, each giving nine resumption conditions. This made 144 trials (16 × 9), which were presented in random order to all participants. Figure 1 illustrates the procedure.

Results

Figure 2 presents the results obtained for the two groups of participants (experts and novices) as a function of the shift size.

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[1] Hubbard (2005) suggested that RM serves to fill in the gap generated by the time taken to process visual information. During the perception of moving objects, the cognitive system takes some time, albeit very short, to process incoming information. Given that the principal characteristic of moving scenes is perpetual change, the mental representation of the object's spatial location would always be delayed. RM is thought to correct this error by way of a spatial representation that incorporates the continuous spatial change.

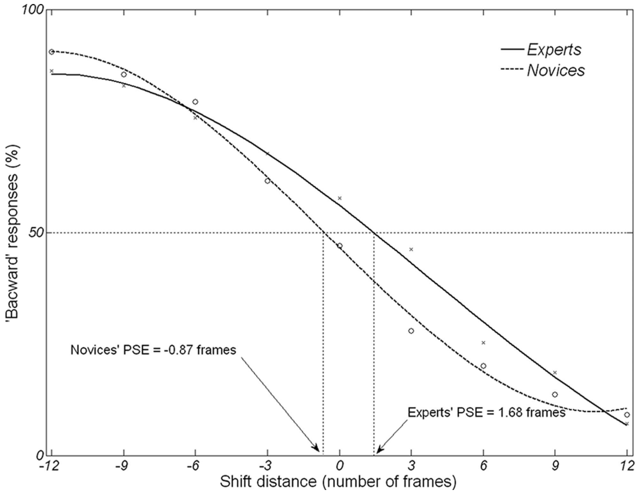

Figure 2. Percentage of backward responses, by expertise level, shift direction, and shift distance in Experiment 1. PSE = point of subjective equality.

The dependent variable was the percentage of "backward" responses.

The average response times (experts = 1,396,552 ms, *SE* = 86.08; novices = 1,350,877 ms, *SE* = 72.75) indicate that all participants answered before the landing of the aircraft (about 15 s after the interruption). Both means did not differ significantly, $F(1, 34) = 0.1$, $p = .6$.

Analysis of RM magnitude. To assess RM magnitude, we computed the point of subjective equality (PSE) for each subject. This point is the theoretical value of the stimulus the participant considers to be subjectively equal to a standard. It indicates the point of maximal uncertainty. This measure was computed by fitting the distributions of percentages of each participant with a third-degree polynomial in least square sense. Each PSE was calculated from this curve by taking all responses of each participant into account. A positive PSE (i.e., significantly superior to zero) indicated FD. Mean PSE was 1.68 frames ($SD = 2.69$) for the expert pilots and −0.87 frame ($SD = 2.5$) for the novices. The experts' mean PSE was significantly greater than zero, $t(14) = 2.42$, $p < .05$, whereas the novices' PSE was not different from zero, $t(20) = 1.9$, $p = .07$. Experts' mean PSE was significantly greater than the novices' mean PSE, $t(34) = 3.12$, $p < .05$. The positive PSE observed in experts indicates FD. Figure 2 presents the curves for the two groups.

Analysis of the percentage of "backward" responses. An analysis of variance (ANOVA) with expertise as a between-groups factor and shift size as a within-group factor (–12 frames, –9 frames, −6 frames, –3 frames, 0 frame, +3 frames, +6 frames, +9 frames, +12 frames). The expertise factor was not significant, $F(1, 34) = 2.31$, $MSE = 790121$, $p = .1$. The "backward" responses in novices (48.26%) were not significantly different from those of experts (51.9%). The shift size effect was significant, $F(1, 34) = 2.31$, $MSE = 790121$, $p < .0001$. The interaction between expertise and shift size was significant, $F(8, 272) = 3.47$. $MSE = 501.9$, $p < .001$. Planned comparisons show that experts answered "backward" significantly more often than novices for the smaller forward shift (at +3 frames: experts = 46.19%; novices = 27.89%), $F(1, 34) = 11.65$, $MSE = 2930.07$, $p < .01$. For the same-resumption condition, experts answered "backward" more frequently than novices (at 0 frame: experts = 57.61%; novices = 46.93%), $F(1, 34) = 4.88$, $MSE = 998.09$, $p < .05$. Such a difference was not observed for the smallest backward shift (at –3 frames: experts = 67.21%; novices = 61.56%), $F(1, 34) = 1.29$, $MSE = 320.74$, $p = .26$.

Discussion

The goal of this experiment was to determine whether the RM effect is modulated by expertise. The results obtained indicated FD among experts. Their mean PSE was positive (i.e., their point of maximum uncertainty was shifted in the FD direction). In other words, when the expert pilots were processing small forward shifts, they misperceived these forward shifts. This phenomenon, which was not found for the novices, can be interpreted as an anticipation in the direction of motion. By contrast, the results of the ANOVA on the smallest backward-shift (–3 frames) item showed no difference between the pilots and the novices. This finding suggests that, even though the experts were more familiar with the type of environment presented in the scenes, they did not necessarily have a better overall discrimination ability than the novices. No significant difference appeared when we analyzed the slopes of the functions relative to novices and experts, $t(16) = 0.102$, $p = .92$. This suggests that the discrimination ability does not differ between novices and experts. Indeed, the perceptual difference between experts and novices only showed on same resumptions and forward shifts. In these two conditions, the experts answered "backward" more often than the novices did.

To rule out the possibility that the novices were perhaps an outlier group with unusually small RM in general, a control task was proposed to these same novices. We chose the classical (Hubbard, 2001) task of a moving square on a plain background, the same as the one we used in previous research (Blättler et al., 2010). These artificial scenes showed an animated (24 frames/s) black square moving from left to right (5.5°/s) across the screen against a plain, light-colored background. After 2 s of animation, a black screen appeared for 250 ms before the rest of the video was shown in one of the nine resumption conditions: same-resumption condition, forward-shift conditions, and backward-shift conditions, the last two of which had four shift distances each (expressed in number of images): four, eight, 12, and 16 images. This made nine videos per type of scene. Results showed that our novices, as all participants of previous research, exhibited an RM effect. The participants' mean PSE (0.78 frame, $SD = 0.2$) was positive, $F(20) = 3.8$, $p < .01$.

These findings call for two remarks. First, they extend the results obtained by Blättler et al. (2010) to a new domain, airplane piloting. With the acquisition of expertise, FD appears to be greater for expert pilots than for novices in situations that belong to their domain of expertise. The results of Experiment 1 brought out a very surprising finding: the lack of anticipation among novices. Very few studies have found no RM effect in direction of actual motion (see, however, Finke & Freyd, 1985; Verfaillie & d'Ydewalle, 1991). In those rare studies, the absence of an RM effect was ascribed to the lack of motion congruity (Finke & Freyd, 1985) or to the fact that the motion that would be predicted to follow the cut was a movement going in the opposite direction

(Verfaillie & d'Ydewalle, 1991). These two possibilities can be ruled out for our study. The movement we tested was clearly congruent, and there was nothing suggesting that the motion would go in the opposite direction after the cut. To understand the absence of novice anticipation in Experiment 1, two nonexclusive interpretations can be entertained. Either the novices did not anticipate because they had no knowledge in this domain (landing scenes) that they could use to anticipate the motion, or they did not anticipate because the characteristics of the scenes (ISI duration or shift size) did not allow them to implement anticipatory processes. The purpose of Experiment 2 was to test for the potential impact of these two experimental factors.

Experiment 2

The results of Experiment 1 showed that on an RM task using dynamic environments simulating aircraft landings, expert pilots exhibited a displacement of the spatial location stored in memory that was shifted in the direction of motion (FD), but the novices did not. This result is rather surprising given that nearly all experiments conducted so far in this domain have found FD (for a review, see Hubbard, 2005). For example, in a study by Courtney and Hubbard (2008), an RM effect was observed in every situation tested, no matter what instructions had been given to subjects, even instructions purposely designed to counteract the effect. But there is one important difference between our study and most other studies in this field. In "classic" experiments, participants have already encountered visual scenes of varying degrees of similarity to the ones presented. We have all seen many objects or animals in motion since birth, and we all began to experience dynamic situations at a very young age (moving in a stroller, riding a car, etc.). It follows that the lack of FD detection among novices in our study may be due to the lack of a known situation that could serve as a reference. Aircraft landing scenes (from the viewpoint of the pilot) are indeed very different from the scenes presented in traditional perceptive experiments. However, we can propose another interpretation of the lack of a novice RM effect based on the experimental parameters used in Experiment 1. The choices we made for ISI duration (125 ms) and shift size could account for why anticipation processes were not observed among the novices. First, it is possible that the ISI in Experiment 1 was too short, so that there was not enough time for an RM effect to be observed. Freyd and Johnson (1987) showed that the magnitude of FD increases up to 250 ms of ISI. Such an ISI was used in our previous study (Blättler et al., 2010) in which the novices exhibited FD. Thus, it is possible that novices did not have enough time in Experiment 1 to develop their RM. Second, the smallest forward shifts presented in Experiment 1 may still have been too great (i.e., not small enough for FD under 3 frames to show up). We tested the effects of these two factors in two studies (participants in Experiment 2A were different from those in Experiment 2B).

Experiment 2A included two conditions: Condition 1 was a long-ISI condition, where the ISI lasted 250 ms (i.e., twice the duration of the ISI in Experiment 1) and where the shift distances were the same as those used in Experiment 1. Condition 2 was a small-shift condition in which shifts of 0 frame, ±1 frame, ±2 frames, and ± 3 frames were presented (i.e., the biggest shift in Experiment 2 was equal to the smallest shift in Experiment 1) and with an ISI that lasted 125 ms.

Experiment 2B was a long-ISI and all shift-distance condition, with an ISI of 250 ms and shift distances of 0 frame and ±1, ±2, ±3, ±6, ±9, and ±12 frames.

Experiment 2A

Method.

Participants. The participants were 15 novices who did not participate in Experiment 1 (mean age = 29.5 years, *SD* = 6.5). They all had normal or corrected-to-normal eyesight and were unaware of the goals of the experiment.

Materials.

Long-ISI condition. In this condition, the ISI lasted 250 ms (instead of 125 ms as in Experiment 1). The shift sizes were the same as in Experiment 1 (0 frame, ±3 frames, ±6 frames, ±9 frames, and ±12 frames). There were nine shift sizes for each of the 18 scenes, for a total of 162 videos.

Small-shift condition. In this condition, the biggest shifts corresponded to the smallest shifts used in Experiment 1 (3 frames). The shift sizes were 0 frame, ±1 frame, ±2 frames, and ±3 frames. There were seven shift sizes for each of the 18 scenes, for a total of 126 videos. In this condition, the ISI was 125 ms, as in Experiment 1.

In all, there were 288 scenes in the experimental materials.

Procedure. The instructions and task were the same as those in Experiment 1. For the familiarization phase, 18 long-ISI trials and 14 small-shift trials were presented randomly to the participants (these 32 trials were not included in the data analysis). Then the experimental phase began. It consisted of 256 trials (i.e., 144 trials in the long-ISI condition intermixed with 112 trials in the small-shift condition) presented in a different random order for each participant. This meant that all participants performed in both experimental conditions (long ISI and small shift).

Results and discussion.

Analysis of the results in the long-ISI condition (250 ms). Figure 3 presents the data obtained in the long-ISI condition.

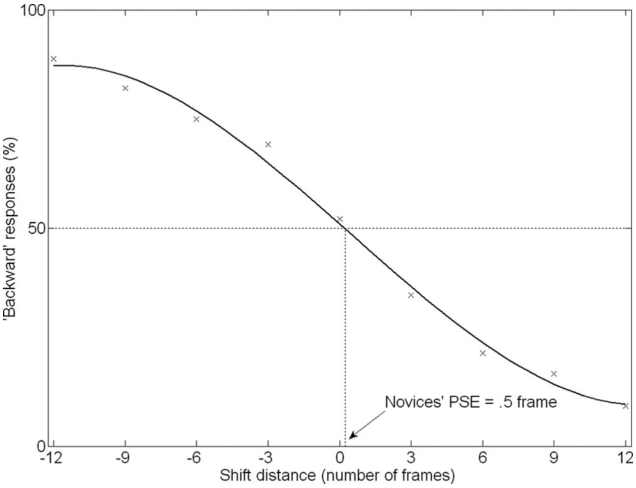

Figure 3. Percentage of backward responses in the long interstimulus interval condition, by shift direction and shift distance in Experiment 2A. PSE = point of subjective equality.

Analysis of RM magnitude. Mean PSE (0.5 frame, *SD* = 3.012) was not significantly different from zero, $t(14) < 1$, $p = .5$.

Analysis of the results in the small-shift condition. Figure 4 shows the results obtained in the small-shift condition.

Analysis of RM magnitude. Mean PSE (0.84 frame, *SD* = 1.07) was significantly greater than zero, $t(13) = 2.96$, $p < .05$. The novices' PSE was positive, which indicates greater difficulty identifying forward shifts and a displacement (in memory) of the scene's position in the direction of motion.

The purpose of this experiment was to test the effect of two experimental factors, ISI and shift size. The results for the long-ISI condition showed that when the ISI was 250 ms, no FD was detected. By contrast, when the shift size was reduced (small-shift condition) while keeping the same ISI as in Experiment 1, FD was obtained. The participants' mean PSE was positive. Thus, we were able to obtain a significant FD in the small-shift condition.

Experiment 2B

The purpose of Experiment 2B was to test whether novices reached their upper limit of anticipation in Experiment 2A. Indeed, Freyd and Johnson (1987) showed that the magnitude of RM is maximum at a certain point in time and then decreases gradually as the delay increases (see also Kerzel, 2002). Thus, two hypotheses were tested. Either novices had reached their upper limit, in which case an increase of the ISI should reduce the extent of FD, or their upper limit was not yet reached, in which case an increase of the ISI would result in an increase in magnitude of the FD. To stay as close as possible to Experiment 2A, participants in Experiment 2B saw all shift sizes.

Method.

Participants. The participants were 36 novices who had not been in Experiment 1 or 2A (mean age = 19 years, *SD* = 2). All participants had normal or corrected-to-normal eyesight and were unaware of the experimental goals.

Materials. The materials were the same as those in Experiment 2A except for the fact that the ISI on small shifts was no longer 125 ms but 250 ms. In this experiment, 13 variations of each of the 18 basic scenes were generated (0 frame, ±1 frame, ±2 frames, ±3 frames, ±6 frames, ±9 frames, and ±12 frames), for a total of 234 videos.

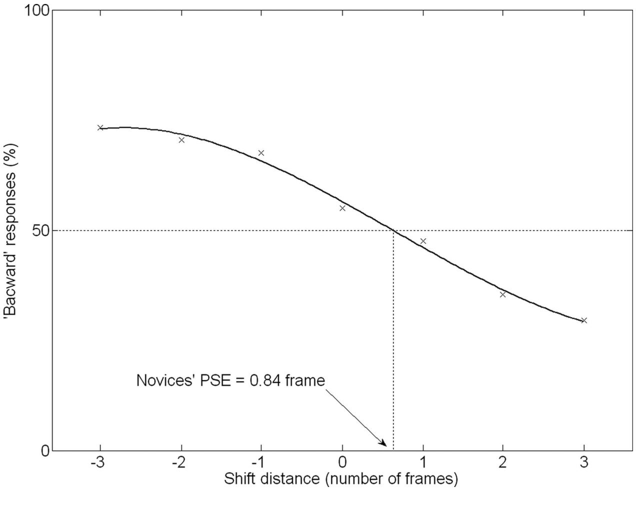

Figure 4. Percentage of backward responses in the small-shift condition, by shift direction and shift distance in Experiment 2A. PSE = point of subjective equality.

Procedure. The instructions and task were the same as those in Experiment 1. For the familiarization phase, 26 trials were presented in random order. Then the 208-trial experimental phase began. All videos were presented in a different random order for each participant.

Results and discussion. Figure 5 shows the results obtained in Experiment 2B.

Analysis of RM magnitude. Mean PSE (−0.02 frame, *SD* = 1.33) did not differ significantly from zero, $t(35) < 1$, $p = .9$.

The purpose of this experiment was to find out whether lengthening ISI on small shifts could increase or decrease FD magnitude among novices. The main result was that the increase (from 125 ms to 250 ms) caused the FD to disappear.

All in all, novices showed FD in one condition, that is, with a very small shift (1 frame) and short ISI (125 ms). These results are different from most of the literature, in which FD was present in the majority of experiments. Here, it was the opposite. The presence of FD occurs only in a few experiments. Therefore, we point out an interesting phenomenon: It is difficult to develop FD for dynamic scenes for which participants had a low level of familiarity.

General Discussion

In both experiments, visual simulations based on synthesized images of aircraft landing scenes, seen from the viewpoint of the pilot, were used in an RM task. We tested expert pilots from the French Air Force, who were very familiar with this type of scene, and novices, who had never seen such scenes. The results obtained pointed out two phenomena: (1) Expertise effects were observed on this RM task. (2) An RM effect was not detected for novices in several experimental conditions, but it was detected in peculiar experimental conditions.

Expertise Effects on This RM Task

The first objective of this study was to determine whether and to what extent FD brings domain-specific knowledge to bear. In a previous study (Blättler et al., 2010), we demonstrated an expertise effect in the domain of automobile driving on an RM task, in which experienced drivers exhibited larger FD than novices in a driving situation but not in situations far removed from automobile driving. Here, we wanted to see whether we could extend these results to another domain, with more highly contrasted levels of expertise. For the realistic dynamic scenes we used, an expertise effect was indeed observed: In Experiment 1, FD was detected only in experts. The mean PSE was positive for experts but not for novices, which indeed reflects FD solely among experts. Other measures specify aspects in which experts differ from novices. First, when the scene resumed at exactly the same point as before the cut, the piloting experts answered "backward shift" significantly more often than the novices did. Second, when the video resumed with a forward shift, the experts again responded "backward shift" significantly more often than the novices did, especially on the smallest forward shifts.

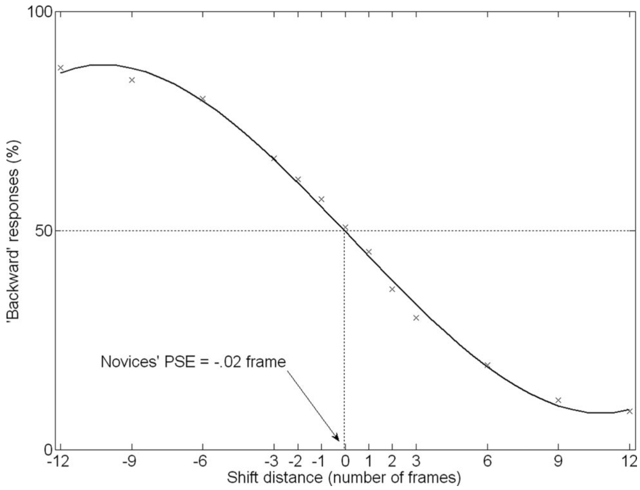

Figure 5. Percentage of backward responses, by shift direction and shift distance in Experiment 2B. PSE = point of subjective equality.

The FD observed here can be considered to reflect very good adaptation by the visual system of experts. In this line, Hayhoe (2009) showed that memory may play a part in controlling visually guided behavior. Observers are thought to learn the dynamic properties of the world in order to direct their gaze where it is needed. In dynamic environments such as driving, they would learn the complex properties of the moving environment. For Hayhoe, evidence of such learning is the fact that saccades are often directed toward a location in a scene in advance of an expected event. For example, in Land and McLeod's (2000) study of cricket, batsmen anticipated the ball's bouncing point so that the eye arrived at that point 100–200 ms before the ball did. The ability to predict where the ball will bounce would rely on previous experience of the ball's trajectory. The saccades were always preceded by a fixation on the ball as it left the bowler's hand, suggesting that the bouncing-point predictions were based on both current sensory data and prior experience of the ball's motion. The authors concluded that observers store internal models of the dynamic properties of the world that can be used to position the gaze in anticipation of a predicted event.

The participants' anticipatory saccades and pursuit movements revealed that acquisition of visual information is planned for a predicted state of the world. Such predictions have to be based on a stored memory representation. And the accuracy of the predictions reveal the quality of the information in the stored memory or internal model. Spatial and temporal accuracy of eye saccades and fine-tuning of these movements following a change in the moving object's dynamic properties would indicate that subjects have an accurate internal model of the object's spatiotemporal path, and that they rapidly update this model when errors occur. As Hayhoe (2009) stressed, the development of internal models occurs over long periods as a result of extensive practice.

The data we collected seem to point in this direction. It takes years of experience before an expert pilot becomes capable of anticipating the spatiotemporal evolution of landing scenes in order to fill in the visual gap in what is perceived. Such anticipation processes are likely to help pilots manage the control strategies they use. For example, scanning strategies may have played a role with the present displays. Following the pioneering work by de Groot (1965) and Chase and Simon (1973), a large number of studies have shown that expertise in a domain considerably modifies the perceptual encoding of domain-specific elements present in the scene (see, e.g., Reingold, Charness, Pomplun, & Stampe, 2001). Thus, it is possible that expert pilots extract different information that promotes RM. Taken together, these results clearly support the hypothesis that RM relies at least partially on specific knowledge stored in long-term memory. Nevertheless, an alternative hypothesis could be proposed. Perhaps people with a high level of RM could be selected or self-selected to be pilots. To test this hypothesis, other research should be developed to test whether pilot candidates appear to be different from other participants—psychology students, for instance—in RM tasks far from landing aircraft. This hypothesis seems relatively unlikely given the results observed in other knowledge domains, such as driving (Blättler et al., 2010) or chess (Chase & Simon, 1973). We acknowledge that this hypothesis has to be seriously considered. But given the results obtained in different domains, we think it is nevertheless justified to continue to argue that RM relies at least partially on specific expert knowledge stored in long-term memory.

RM Among Novice Participants

The RM effect was not detected for the novices in several experimental conditions. In Experiment 1, their PSE did not differ from zero. A few rare experiments have shown that FD can be eliminated when the direction of motion cannot be anticipated (Kerzel, 2002) or when distractors are presented during the retention interval (Kerzel, 2003). Distractors during the retention interval seem to stop the mental extrapolation of the target. The presence of such distractors may disrupt the flow of attention allocated to the moving target and thereby cause FD to decrease.

With this finding in mind, we tested the hypothesis that with a longer ISI, more time could be allotted to the mental extrapolation of the dynamic scene, and that this additional time might allow FD to show up, even among novices. Therefore, in one of the conditions of Experiment 2A, ISI duration was doubled (from 125 to 250 ms) and the same shift sizes were used. The results were very similar to those obtained in Experiment 1. For novices in these experimental conditions, we were not able to demonstrate FD. This brought us to our second question concerning the shift sizes. We hypothesized that the anticipatory time span might have been too short for FD to appear in novices on the shift sizes used. Therefore, in the second condition of Experiment 2A, smaller shifts were presented (1, 2, and 3 frames) with an ISI of 125 ms, as in Experiment 1. In this condition, FD was indeed observed. The PSE of the novices was significantly different from zero (0.84 frame on average). Their maximum uncertainty point was between 0 frame and 1 frame.

In Experiment 2B, we tested the hypothesis that increasing the ISI from 125 to 250 ms would increase the magnitude of FD when the shifts were small. But once again, no FD was found in this condition. A hypothesis would be that novices could use local strategies rooted in specific motion, or nonmotion, cues. As a matter of fact, if forward- and backward-shift probes are compared after the cut of a dynamic scene, at the moment when the video resumes, nonmotion cues might be available (e.g., in Figure 1, there is more grass visible prior to the runway in the backward-shift probe than in the forward-shift probe). It would be possible that novices might have used cues such as these in rendering their judgments. The use of such nonmotion cues would be consistent with the lack of FD for novices in Experiment 1. Anyway, we were able to provide evidence of FD in only one very specific condition (Experiment 2A): a very small shift (1 frame) and a short ISI (125 ms). Among the novices—who were true novices for the types of dynamic scenes presented here—the FD observed here was very tenuous and labile because it disappeared when the visual interruption time was too great. It appears that minor variations of the experimental conditions can lead to very different results concerning the RM effect. Such a result was observed by Thornton and Hayes (2004, Experiment 3), the responses being less biased in the direction of the movement for one of the stimuli (the "railway station") than for the other stimuli. Such results are interesting because they stress the fact that if shift differences are properly calibrated, RM may be found in novices.

Nevertheless, in our experiment, even in the best configuration of shift and ISI, the positive PSE that was observed in novices was very small. Perhaps, this finding can be interpreted simply in terms of low-level processes taking place at the retinal level that do not depend on knowledge acquired with experience. In line with this, Berry, Brivanlou, Jordan, and Meister (1999) showed that anticipation of moving stimuli begins in the retina. These authors recalled the results of experiments on motion perception conducted by Nijhawan (1994, 1997). In those studies, subjects were shown a moving bar sweeping at a constant velocity, with a second bar flashing briefly in alignment with the moving bar. When asked what they perceived at the time of the flash, observers reliably reported seeing the flashing bar trailing behind the moving bar. This effect has been confirmed repeatedly (Baldo & Klein, 1995; Purushothaman, Patel, Bedell, & Ogmen, 1998; Whitney & Murakami, 1998), and various high-level processes have been used to explain it (e.g., a time lag due to the attention shift). To determine whether processing in the retina contributes to the flash bar effect, Berry et al. recorded the spike trains of ganglion cells in the isolated retina of tiger salamanders or rabbits and then analyzed the neural image of a moving bar at the retinal output. The results showed that the moving bar elicited a moving wave of spike activity in the retinal cell population. Rather than lagging behind the visual image, the population activity traveled near the moving bar's leading edge. This response was observed for a wide range of speeds and was interpreted as a compensation for the visual response latency (30–100 ms). In sum, the authors showed that the extrapolation of a moving object's trajectory begins in the retina. By analogy, we are tempted to hypothesize that for the novices in our experiments, who had no experience of the dynamic visual scenes presented, retinal anticipation may partially or totally account for the observed FD, which was very weak, very small (a few tens of milliseconds), and very labile given that it disappeared when the ISI was long (250 ms). For small forward shifts (here, 1 frame) followed by a brief perceptual interruption (125 ms), novices may store a memory trace of the position extrapolated by the retinal cells. But when the interruption is longer (250 ms), the memory trace is erased, so an RM effect cannot be demonstrated.

Another point concerns the role played by RM during the perception. The speed with which the experts are able to develop FD in realistic scenes may suggest that RM can play an online role in view integration. This assumption of an online role of RM is based on research by Freyd and Johnson (1987) showing that FD can be obtained from 10 ms and on research on transsaccadic memory. Transsaccadic memory, which is a visual short-term memory and not a sensory memory (Irwin, 1991), contains some components about motion anticipation (Verfaillie, De Troy, & Van Rensbergen, 1994). Thus, it is likely that RM can be used to compensate for some constraints, such as neuronal delays (Kerzel & Gegenfurtner, 2003), but also to compensate for the transient blindness occurring during ocular saccades or for a longer period (e.g., when a driver looks at the dashboard a few instants before looking once again).

In conclusion, the results of the experiments reported here suggest the potential collaboration of two types of anticipatory processes. For experts, the development of high-level semantic and strategic knowledge would allow them to extrapolate visual scene continuity. Novices, on the other hand, who are unfamiliar with the scenes presented, would rely mainly on sensory information arriving at the retina when the cut occurs. Memory traces stored by novices with no prior experience of the dynamic visual scenes would vanish very rapidly, whereas those of experts who are highly familiar with the scenes would support greater and more durable anticipation. This raises the question of the relative weights of the different anticipation processes at play, from retinal anticipatory processes on up to higher level anticipatory processes based on semantic and strategic knowledge acquired with expertise.

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