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EXTRAPOLATION OF THE INTERSECTION OF TWO TRAJECTORIES ON A 2D DISPLAY: EVIDENCE OF BIASES

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The aim of this study[1] is to understand how people can extrapolate the collision point of two static stimuli representing aircraft on a 2D display. The task was to point out with a mouse cursor where the two aircraft' trajectories would intersect. The presented configurations varied with angle and distance between the two stimuli. First, results show an effect of the distance and the angle between the two aircraft on the accuracy of the estimation of the collision point as well as on decision times. Secondly, participants tended to produce significantly more responses within the triangle formed by the two aircraft and the actual crossing point. In other words participants tended to undershoot the intersection point of the two trajectories. Finally, we produce dispersion graph to visualize how the answers were distributed on the display.

Introduction

Air Traffic Controllers (ATC) ought to ensure the security and the flow of air traffic. Controllers' performances rely on their capacity to extrapolate the actual position of an aircraft to a future position. Such extrapolations are required to make decisions on the presence or absence of separation loss with another aircraft.

ATC spend 80% of their time watching the radar display, 13% is dedicated to the flight strips and 5% to watch input displays (Karsten *et al.*, 1975). A more recent study (Willems *et al.*, 1999) shows that 75% of eye fixations are on the radar display and 69% of this time is dedicated to the aircraft. So the radar display may be the principal medium where visual information about the traffic status can be gathered.
The conflict detection task involves a large workload amount. Anticipation of the future position of aircraft is highly dependent on working memory (Wickens *et al.*, 1997). Understanding cognitive and perceptive mechanisms is necessary to identify human limitation in a conflict detection frame.

If one wants to explain conflict detection between two aircraft, two concepts must be presented (Xu & Rantanen, 2003): "Relative judgment" (*RJ*) (Law *et al.*, 1993; Tresilian, 1995) and "Prediction Motion" (*PM*) (Tresilian, 1991, 1995). Relative judgment is the capacity to assess which aircraft will cross the intersection point first. The prediction motion is the capacity to time the moment when the aircraft would collide. So, these two activities enable the controller to know which one of the two aircraft will arrive first at the intersection of the two trajectories and when separation is lost. Usually, RJ and PM studies use a time to collision task (TTC). In the first version of the TTC task participants have to judge which of the two aircraft would reach the contact point first (Law et al., 1993). In the second version participants view the movement of two flashing stimuli until they disappear from the display. They have to judge when these two stimuli would intersect (Kimball, 1970; Kimball *et al.*, 1973). These studies showed that judgments are highly influenced by the aircraft spatial configuration: convergence angle, relative speed, and distance between the two aircraft.

In this study we assume a reductionist standpoint and we concentrate on the intersection localization subpart of the task, often evoked, but not often clearly explained. Indeed to produce accurate judgments in TTC tasks, the ATC must extrapolate the localization of the intersection point so as to assess the distance between the aircraft and the intersection point. In addition, the ATC must simultaneously consider aircraft speeds and the crossing point position to judge which aircraft will pass this point first—and when. That is, to assess which aircraft will pass the intersection first or the lapse of time before an aircraft pass this point the ATC must have a representation of that point. It is unclear how one could produce RJ or PM judgments without such extrapolation.

Understanding the mechanism of extrapolation of the intersection point of two trajectories in an exocentric

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view (namely, on a radar display) might in turn help to partially explain the role spatial configurations play in controller difficulties.

This study explores the hypothesis that genuinely perceptual biases alter conflict detection.

Methods

Participants

556 persons proceeded with the experiment, which was included in a series of tests designed to select candidates for entering the ENAC (École Nationale d'aviation civile, Toulouse, France, April 2006), the French school for civil pilots. Their ages ranged from 17 to 30 years (mean: 20, *SD*: 2.5) and all had normal or corrected-to-normal vision. There were 508 men (91.4%) and 48 women (8.6%). Education level was distributed as follow: 46 A-levels (8.3%), 469 License (84.3%), 41 Master or more (7.4%). All participants were in competitive conditions.

Apparatus and stimuli

Stimuli were presented on 17-in CRT displays with a resolution of 1024x768 pixels and a refresh rate of 75Hz. Participants used optical mice. Instructions were both presented as a text on the screen and orally by means of individual headphones. The background color was yellowish. Each aircraft was represented as a red-triangle shape with a red line indicating the direction of displacement (see Figure 1). The mouse cursor was a standard arrow shape (windows XP pro). At the screen bottom a green scrolling bar exhibited the time available to the end of the test. Participants provided their responses by clicking on the screen at the location where they supposed the intersection point to be. Only after the first click of the trial a validation button was displayed. However, changes could be made by simply clicking to new locations until validation.

Stimuli configuration varied on convergence angle (45°, 90° and 135°) and on distance between aircraft and the intersection point of the trajectories. Two different distances were used: the distance between an aircraft and the intersection point could be 5° of angle corresponding to the parafoveal area of vision (*Pf*) or 10° angle corresponding to the periphery of vision area (*Per*). The aircraft/intersection locations were pseudo-randomly rotated before each trial. All participants have seen the same set of stimuli, with the same rotation and in the same order due to competitive examination conditions. Participants had to estimate six different spatial configurations: 3 angles * 2 distances.

Procedure

The experiment took place in a room with 12 PCs. There were 12 participants per session. The room lightning was controlled to avoid any reflecting phenomena on the display. Participants were placed in front of a computer at 50 cm from the monitor.

Figure 1. Test display's screenshot

Time was limited to 240 seconds for the complete set of trials in the test. Participants were told not to use any physical means which could help decision-making. Once the instructions were understood the candidates had to click to start two practice trials. After each practice trials, participants were showed the actual location of the intersection. Then experimental trials followed, with no feedback.

Data and analysis

Response time in milliseconds (ms) and accuracy were recorded. Response accuracy was the distance between the participant's response and the correct location of the intersection point in pixels[2]. Repeated measures ANOVAs were processed with a 3 angle x 2 distance design. As the participants were in competition condition some of them did not complete the entire test. Missing data were replaced by the means of the series. Post-hoc comparisons were realized using Scheffé tests.

Results

Accuracy

There was significant main effect of distance ($F(1,555) = 510.9$, $p<.001$), angle ($F(2, 1100) = 68.97$, $p<.001$), and an interaction between angle and distance ($F(2,1100)= 8.71$, $p<.001$). Closer stimuli led to more accurate extrapolations. The accuracy

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[2] In this configuration 1cm = 30 pixels

was optimal for 90° angle but lower for 45° and 135° angles (cf. Table 1). Post-hoc pairwise comparisons show that in Pf distance condition the accuracy between 45° and 135° angles are the same but in Per condition we have a decreasing accuracy for the 135° angle compared to 45° angle (Figure 2 and Table 1).

Response Time

There was a significant effect of the distance ($F(1,555)= 349.16$, $p<.001$), angle ($F(2, 1110)= 8.89$, $p<.001$) and an interaction between angle and distance ($F(2,1110)= 7.79$, $p<.001$). That is, the larger the distance, the longer the time to make a judgment. Globally the time to make a decision for a 90° angle is shorter than 45° and 135° angles (cf. Table 1). Post-hoc pairwise comparisons show that response times for 45° and 135° angles are not significantly different. (cf. Figure 3). In Per condition, all responses times are equal independently of the angle.
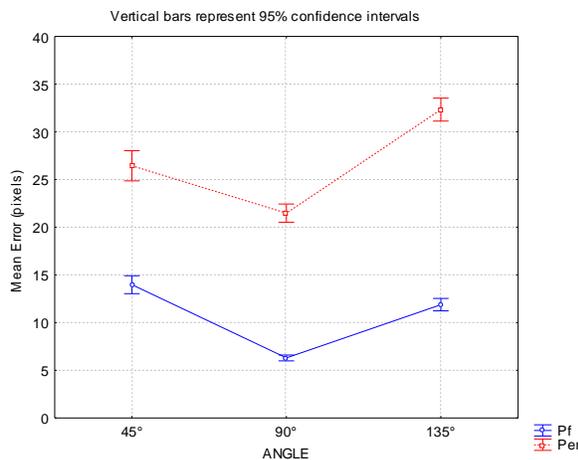

Figure 2. Mean accuracy (in pixels)

Table 1. Mean gap in pixels between response and intersection point and RTs in seconds as a function of distance and angle (*N*=556)

Distance	Angle	Gap Mean SD	RTs Mean SD
Pf	45°	13.98 (11.3)	10.6 (5.3)
	90°	6.30 (3.6)	9.1 (4.1)
	135°	11.89 (7.8)	10.5 (5.0)
Per	45°	26.45 (19.0)	13.3 (7.9)
	90°	21.48 (11.5)	13.4 (6.8)
	135°	32.33 (14.5)	13.7 (6.8)

Pf: parafoveal distance (5°), Per: periphery (10°)

Undershooting Effect

We computed the number of responses in the area formed by the two aircraft's trajectories relative to the global space (see Figure 4). Participants tended to undershoot the extrapolation point, that is, they produce more responses in the area formed by the two trajectories (namely internal angle area) before the intersection point except for the Per-90° condition: 75.8% of the responses were in the internal angle area versus only 24.6% in the much larger remaining area (all $p< 0.01$).

Deviation on cardinal axis

The mean gap provides error sizes, but does not describe how errors are structured. We computed the gap, horizontally x (ε_x) and vertically y (ε_y), between the barycenter of responses and the intersection point of the two trajectories.
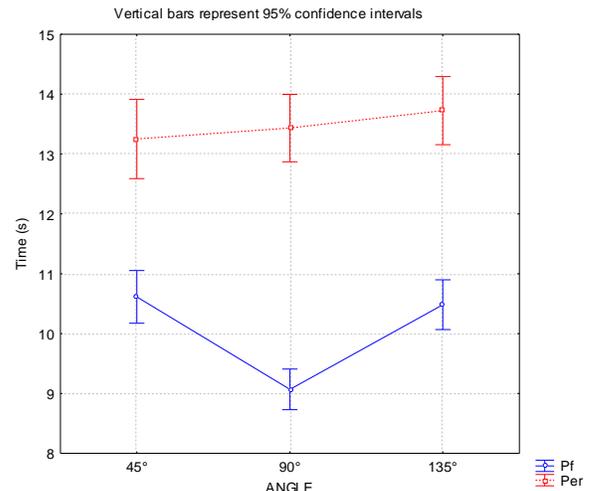

Figure 3. Time means (s) for decision making

The origin was the top left corner of the screen. Values ranged from 0 to 1024 rightward (*x* axis) and from 0 to 768 downward *(y* axis). Table 2 analyzes the gap between the intersection point and the barycenter of responses. For example, a negative gap in *x* indicates a barycenter on the left of the intersection point. A negative gap in *y* indicates a barycenter above the intersection point. Deviations were statistically tested by means of one-sample *t*-tests against 0.
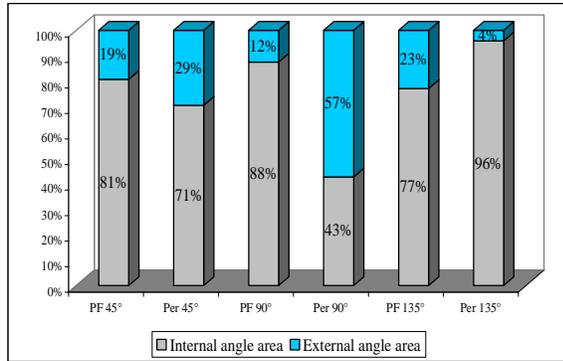
Figure 4. Proportion of response in
the internal angle area

Table 2 shows that participants tended to bias their estimation downward the intersection point. In the Pf condition, this effect was present in the 45° and 90° angles but not in the 135° angle. Only the 90° angle exhibited a strong downward effect size[3] (d= .87). For 45° and 135° angles, effects were probably negligible (respectively d= .10 and d=.14). In the Per condition we can see a strong downward effect for 90° and 135° angles (d= 1.11 and d= 1.07) but a medium-large upward effect in the 45° angle.

Table 2. Gap between groups of responses dots
barycentre and intersection point
(N=556)

Distance	Angle	Axis	Mean	SD	Mean Error	d	t
Pf	45°	x	-0.64	4.30	0.18	0.15	-3.52
		y	-1.72	17.17	0.73	0.10	-2.36
	90°	x	-1.49	4.06	0.17	0.37	-8.63
		y	-3.79	4.34	0.18	0.87	-20.58
	135°	x	-6.15	13.34	0.56	0.46	-10.86
		y	4.86	33.75	1.43	0.14	3.40
Per	45°	x	6.25	29.59	1.25	0.21	4.98
		y	5.67	9.56	0.40	0.59	13.97
	90°	x	6.68	13.36	0.57	0.50	11.79
		y	-14.10	12.68	0.54	1.11	-26.22
	135°	x	8.71	21.64	0.92	0.40	9.49
		y	-23.18	21.75	0.92	1.07	-25.14

Pf: parafoveal distance (5°), Per: periphery (10°)
All comparison means are significant (p<.001)

Table 2 shows a reversal of the deviation on the *x* axis: in the Pf conditions there is a leftward effect whereas in the Per conditions there was a rightward effect. However, effects were very small in the Pf-45° conditions and only reach significance due to the large number of participants. Effect sizes were larger in the other conditions except Pf-135° y axis.

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[3]   Cohen's *d* was used to estimate the size effect. Conventionally, an effect is low if .20<*d*<.50, medium if .50<*d*<.80 and strong if *d*>.80

Graphs 1 to 6 report dispersion/density graphs so as to investigate more qualitatively the dispersion of responses as a function of the distance and the angle. Density was computed as the number of responses within a 5-pixel radius. The colour of plots varies as a function of density (D). Plots are red when D > 100, orange when D∈]80;100], yellow when D∈]60;80], green when D∈]40;60], clear blue when D∈]20;40], and deep blue when D<20. The aircraft are represented by red dots; their direction is represented by a full white line until the intersection point and a white doted line beyond. Note that intersection point is always placed at the graph center.
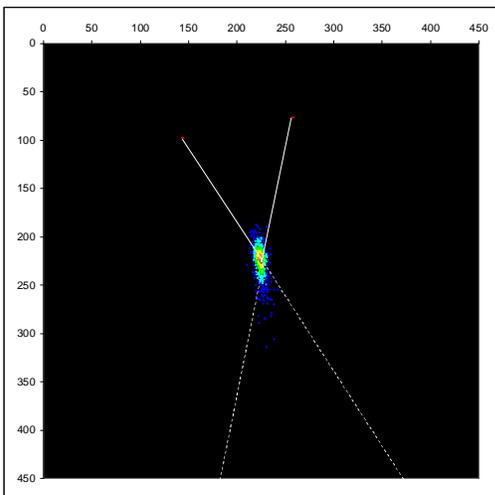
Conclusion and Discussion

This study aimed at understanding how people assess the intersection point of two crossing trajectories. Participants were told to point out their estimation with a mouse cursor while viewing a configuration of two stimuli representing two planes. Configurations varied in (1) the angle formed by the two trajectories, and (2) the distance between the aircraft and the intersection point. Our results show a significant effect of the angle and the distance: 90° angle produces the best accuracy (vs. 45° and 135° angles conditions). Distance was also a significant factor with more distant stimuli producing greater inaccuracy. Moreover, participants tended to assess the collision point closer than its actual position.

At least two concepts used in perception and vision studies could provide some explanations: the *foveal bias* (Kerzel, 2000; Mateeff & Gourevich, 1983; Müsseler *et al.*, 1999; Van Der Heijden *et al.*, 1999) and the *gravity effect* (Hubbard, 1995).
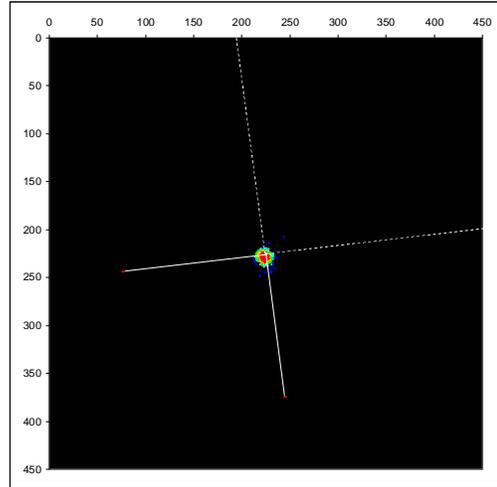
The idea in the foveal bias is that stationary objects in the peripheral area of vision tend to be localized toward the fovea. Indeed for the task proposed here, participants had to scan the two aircraft trajectories to extrapolate the intersection point. Here is the explanation we propose: Participants scanned alternatively the aircraft positions and an estimated point as the intersection point. While they fixed the estimated intersection point they could see the aircraft in their periphery area of vision. As aircraft were stationary, only the estimation of their intersection point could be displaced. Consequently when participants had to decide the position of the intersection point their estimation was biased toward the stationary objects, that is, toward the aircraft. This hypothesis could explain (i) why the majority of responses were within the angle formed by the two trajectories and (ii) why estimations were more accurate in Pf condition.

Gravity effect is defined by the tendency to bias downward the vertical or horizontal movement of a stimulus. This effect could explain the shape of the group of response dots in Pf-45°, Pf-90°, Per-90°, Per -135° conditions which seem to be distorted downward the screen. Nevertheless, the gravity effect can not explain the shape of the group of response dots in the Pf-135° and Per-45° conditions which are distorted upward.

We think that these two effects are important for the extrapolation. But these two biases cannot explain the responses made outside the internal angle area. However, another explanation could complete the analysis of our results. This explanation derives from an analysis of the perceptual strategy used to extrapolate the intersection point. We assume that participants chose a referent aircraft (let us call it the "anchor") from which they extrapolate a trajectory to an area in which the intersection point might be. When this area is determined, they extrapolate the trajectory of the second aircraft until the area previously considered. By looping over these two extrapolations, the target area would be progressively refined until a "satisfying" answer can be provided.
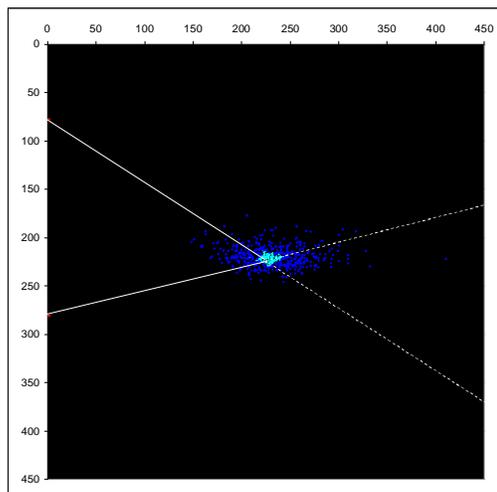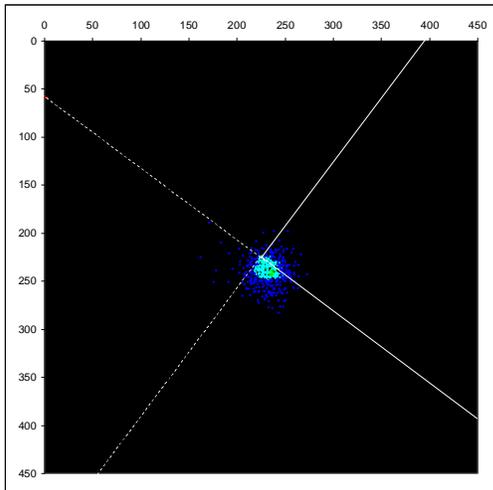

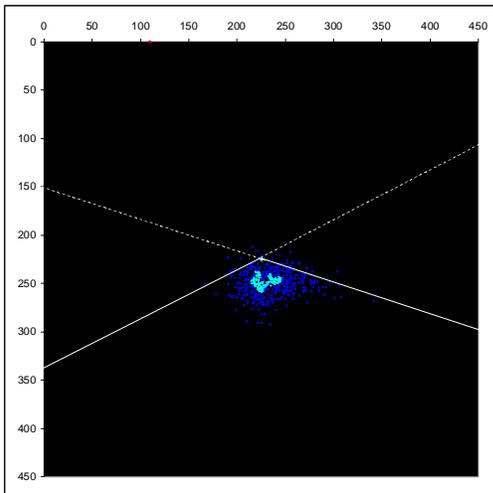**Graph 2.** Answer dispersion, angle 90°, distance Pf
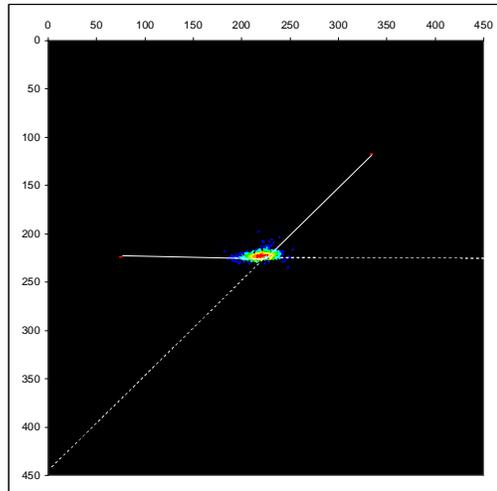
Graph 3. Answer dispersion, angle 90°, distance Pf

Graph 1. Answer dispersion, angle 45°, distance Pf

Graph 4. Answer dispersion, angle 45°, distance Per

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Graph 5. Answer dispersion, angle 90°, distance Per

Graph 6. Answer dispersion, angle 135°, distance Per

Graph 3 can illustrate this strategy and give us some clues to understand how the referent aircraft would be chosen. Indeed, we can observe that the group of response dots is principally horizontal and is deformed toward the top of the screen, that is, toward the second aircraft. Consequently a conceivable explanation is that the referent aircraft is the one which is the most horizontally oriented. Participants would extrapolate its trajectory first and intersect it with the second aircraft trajectory. In doing this participants would tend to bias the estimation of the intersection point toward the second aircraft due to the foveal bias. Such an explanation brings interest to the new problem of eliciting the conditions that preside over the choice of a particular aircraft as referent. As mentioned above, our idea is that the referent aircraft is chosen due to its orientation: participants would choose for referent the most horizontally or vertically oriented aircraft trajectory.

When no stimuli can provide such a particular trajectory, the referent plane would be randomly chosen. This explanation could shed light on the shape responses, which seem to be distributed around the angle's bisector. Consequently, the orientation of the system Stimuli/Intersection point is an important factor which could influence the perceptual strategy and thus the accuracy of the estimation of the intersection point. Future studies are under preparation to test this hypothesis.

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