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EXPERIMENTAL ECONOMICS LABORATORY

Alessandro Innocenti

Alessandra Rufa

Jacopo Semmoloni

Cognitive Biases and Gaze Direction: An Experimental Study

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COGNITIVE BIASES AND GAZE DIRECTION: AN EXPERIMENTAL STUDY

Alessandro Innocenti
Department of Economic Policy, Finance and Development (DEPFID)
University of Siena

Alessandra Rufa
Perception and Eye-Tracking Lab, Department of Neurological and Behavioral Sciences
University of Siena

Jacopo Semmoloni
Perception and Eye-Tracking Lab, Department of Neurological and Behavioral Sciences
University of Siena

Abstract. This paper investigates the validity of the model of dual processing by means of eye-tracking methods. In this theoretical framework, gaze direction may be a revealing signal of how automatic detection is modified or sustained by controlled search. We performed an experiment by using a stylized decisional framework, i.e. informational cascade, proposed by economists to investigate the rationality of imitative behavior. Our main result is that automatic detection as revealed by gaze direction is driven by mechanisms that are dependent on cognitive biases. In particular, we find significant statistical correlation between overconfident subjects' first fixation and their revealed patterns of choice. This implies that gaze direction is driven by cognitive processes in a way that is not necessarily consistent with the efficient processing of information.

JEL classification: C91, D82, D83, D87
Keywords: informational cascades, overconfidence, eye-tracking, information processing

1. Introduction

The role of the visual system in the functioning of human brain has been the object of investigation for decades. The passages leading from the electrochemical signals transmitted by the retina to the brain for neuronal processing have been exhaustively described by cognitive scientists and neurobiologists. What remains still controversial is how these neurobiological processes are first activated and finally translated in actual decisions. Both the mechanisms underlying gaze direction and orienting behavior and the relations between the processing of visual inputs and decision-making are currently scrutinized by a variety of different approaches with conflicting results. Since the 1970s a lot of experimental and theoretical work has been devoted to describe attention orienting as a dual processing activity (Schneider and Shiffrin 1977, Shiffrin and Schneider 1977, Cohen 1993, Birnboim 2003). Schneider and Shriffin (1977, p. 4) define selective attention as "control of information processing so that a sensory input is perceived or remembered better in one situation than another according to the desires of the subject". Being information processing capacity limited, individuals are inclined to address only a limited subset of all the available information. This selection process operates according two different patterns: controlled search and automatic detection. Controlled search is a serial process that uses short-term memory capacity, is flexible, modifiable and sequential. Automatic detection works in parallel, is independent of attention, difficult to modify and suppress once learned.

This characterization suggests a parallelism between information processing and the dualism between associative and rule-based reasoning (Sloman 1996). The theory of dual reasoning holds that cognitive processes are of two types, named System 1 and System 2 (Stanovich and West 2000, Kahneman and Frederick 2002). System 1 includes all the processes characterized by automatic, associative functioning and heuristic purposes, while System 2 encompasses all the rational, rule-based and analytic processes. The main difference between the two is that System 1 is activated immediately and often unconsciously by external stimuli, while System 2 is slower and deliberately controlled. Kahneman and Frederick (2002, p. 53) describe the interaction between the systems as follows: “Highly accessible impressions produced by System 1 control judgments and preferences, unless modified or overridden by the deliberate operations of System 2.” It has also been argued, by developing Vygotsky’s (1943/1987) classical argument, that rule-based reasoning of System 2 could be internalized by System 1 through experience (Hinton 1990). By repeating mental associations over time, people generate automatically intuitive responses that once were the outcome of sequential steps of analytic thinking. Moreover, being both System 1 and 2 also an evolutionary product, it does not necessarily follow that errors on search and information processing pointed out from the heuristics and biases literature are universal. On the contrary, people heterogeneity can be the result of individually specific patterns of interaction between the two systems.

In this theoretical framework, if it is assumed that eye movements and attention shifts are tightly tied, gaze direction represents a signal of how automatic and immediate reactions to visual stimuli are modified or sustained by more conscious and rational processes of information processing (Armel et al. 2008). To investigate this issue, it is useful to consider decision processes that are not driven by individual preferences but related to a future event to be guessed on partial-information clues. In decisions under uncertainty, factors like subjective inclinations or tastes are not present and visual attention can be investigated in a neutral setting. In a previous set of experiments, Shimojo et al. (2003) tested how subjects orient gaze in both preference and non-preference tasks. Their main result is that, in choices between two alternative forced-choice tasks, subjects exhibit a tendency to look increasingly towards the chosen event. This "gaze cascade effect" would support the hypothesis that gaze participates directly in the decision formation process. The brain would use attention orienting to reinforce choice by increasingly looking at the eventually chosen event and by decreasing inspection time for the other one. This finding would imply that gaze bias can be interpreted as preference at subconscious level.

To investigate this issue, we performed some experiments by using a stylized decisional framework, i.e. informational cascade, devised by economists to investigate the rationality of imitative behavior. In this non-preference task, experimental subjects are arranged in a pre-determined order and took sequential decisions under uncertainty. They are asked to guess an event about which they have probabilistic assessments, which are both private and publicly revealed. We analyzed the process of detecting these partial-information signals by means of eye-tracking methods.

Our main result is that automatic detection as revealed by gaze direction is driven by mechanisms that are dependent on individually specific cognitive biases. In particular, we find significant statistical correlation between subjects' first fixation and their revealed patterns of choice. Overconfident subjects, who rely exclusively on private information to take decisions, look initially at their own private signals by displaying a mechanism of attention orienting seemingly dependent on System 1, while Bayesian subjects, who process rationally both private and public information, do not exhibit gaze biases. Moreover, we do not find evidence supporting the gaze cascade effect. In terms of dual theory, our results confirm the hypothesis that cognitive processes classified as System 1 determines automatic detection and that patterns of interaction between

System 1 and System 2 revealed by attention orienting are individually specific and cognitively based. Gaze direction is driven by cognitive processes in a way that is not necessarily consistent with the efficient processing of information.

2. Procedure and Design

A key issue to be investigated in the dual system of reasoning is how System 1 is activated. These automatic reactions are supposed to be largely dependent on the sedimentation of the evolutionary processes in a way that is idiosyncratically determined. Consequently, these factors may differentiate among individuals in a way that is difficult to determine. Our experimental framework intended to provide evidence of the way gaze orientation differentiates among subjects when facing a decision under uncertainty.

The term of informational cascades was introduced to identify herding behavior in a situation where a sequence of decision makers are endowed with private information to predict an uncertain event and their prediction is made publicly available. An informational cascade occurs when subjects imitate previously observed choices by neglecting the content of their private information. (Banerjee 1992, Bikhchandani et al. 1992).

The experimental design assumes that two future events, A and B, may occur with equal probability. To choose between them subjects observe a signal, drawn independently and individually by the same probability distribution, which has a two-thirds chance of indicating the occurrence of the future event. If the signal *a* is observed, the probability of the event A occurring is 2/3 and B occurring is 1/3, while if the signal *b* is observed, the probabilities are reversed (1/3 for A and 2/3 for B). Subjects are asked to choose sequentially between the two states and they receive a monetary reward for a correct prediction. Subjects' choices, but not private signals, are publicly released.

By assuming that all subjects are rational and process information according to Bayes' rule, they will predict the event indicated as more probable by the combination of private signals and publicly known predictions. This implies that the choice of the first decision maker reveals the private signal he has drawn. For example, if he chooses A, later decision makers will infer that he has observed the signal *a* $[\Pr(a|A)=2/3 > \Pr(a|B)=1/3]$

If the second decision maker observes the same private signal *a* he will predict accordingly. If she receives the other signal *b*, he will assign a 50% probability to the two events and both predictions will be equally rational. Let us assume that the second decision maker chooses A.

The third decision maker, when asked to choose, will observe two previous choices of A. If her private signal is *b*, it will be rational to ignore this private information and to predict A as the previous choosers. In this way, an information cascade is formed.

In formal terms, if (*a*, *b*) indicate the numbers of signals *a* and *b* received or inferred, Bayes' rule impose to calculate the probability of the event A in the following way:

$$\Pr(A|a,b) = \frac{[\Pr(a,b|A)\Pr(A)]}{[\Pr(a,b|A)\Pr(A) + \Pr(a,b|B)\Pr(B)]}$$

In the example above, the third decision maker observes two inferred signals *a* and receives only one signal *b*. In this way, the probability is:

$$\Pr(A|a,b) = \frac{(2/3)^2(1/3)(1/2)}{(2/3)^2(1/3)(1/2) + (1/3)^2(2/3)(1/2)} = 2/3$$

It should be noticed that, being signals balanced [$\Pr(A|a) = \Pr(B|b) = 2/3$], the difference in the number of signals *a* and *b* inferred or observed determines the more probable event. In this simplified case, Bayes' rule corresponds to a very simple and intuitive counting heuristic, which is easily computable. In the example above, the third decision maker has to count two previous choices over the only one private signal to determine her choice of A as rational.

A key assumption of the information cascades model is that decision makers behave rationally in processing all the available information in order to decide if imitate or not previous choices. But experimental evidence points out how some subjects exhibit various cognitive biases in deciding if entering or not a cascade.

Anderson and Holt (1997) show that one third of the subjects exhibit a tendency to rely on the simple counting of signals in an experimental design in which signals were unbalanced. Nöth and Weber (2003) give evidence that subjects' overconfidence consistently explains many observed deviations from Bayes' rule.

To investigate if cognitive biases have some relationships with gaze direction we replicated Anderson and Holt's design with some modifications.

The experiments were carried out in the spring of 2007. We submitted our design to 81 students of the University of Siena (41 female and 40 male; mean age 22.4 years). They were recruited through notices posted on the web pages and around the campus of the university. The experiment was computerized. The participants received a participation fee of 5 euros and were also paid according to the euros earned with the experiments. The average earning was 21.4 euros.

We ran nine sessions and two different treatments. Table 1 presents the number of participants for each session and treatment.

Table 1. Summary of the experimental design

Session	Treatment	Participants (women + men)
1	A (FC left - PD right)	9 (4 + 5)
2	A (FC left - PD right)	9 (5 + 4)
3	A (FC left - PD right)	9 (6 + 3)
4	B (PD left - FC right)	9 (4 + 5)
5	B (PD left - FC right)	9 (5 + 4)
6	B (PD left - FC right)	9 (5 + 4)
7	A (FC left – PD right)	9 (3 + 6)
8	A (FC left - PD right)	9 (5 + 4)
9	A (FC left - PD right)	9 (4 + 5)
Total		81 (41+40)

Before the starting of each session, the experimenter showed to the nine participants the content of two small envelopes, marked respectively with a red square and with a red circle. The square envelope contained two red squares cards and one red round card, while the circle envelope contained two red round cards and one red square card. Then the experimenter went to an isolated box, where on the basis of a dice roll he placed the content of one of the two envelopes within a larger opaque unmarked envelope.

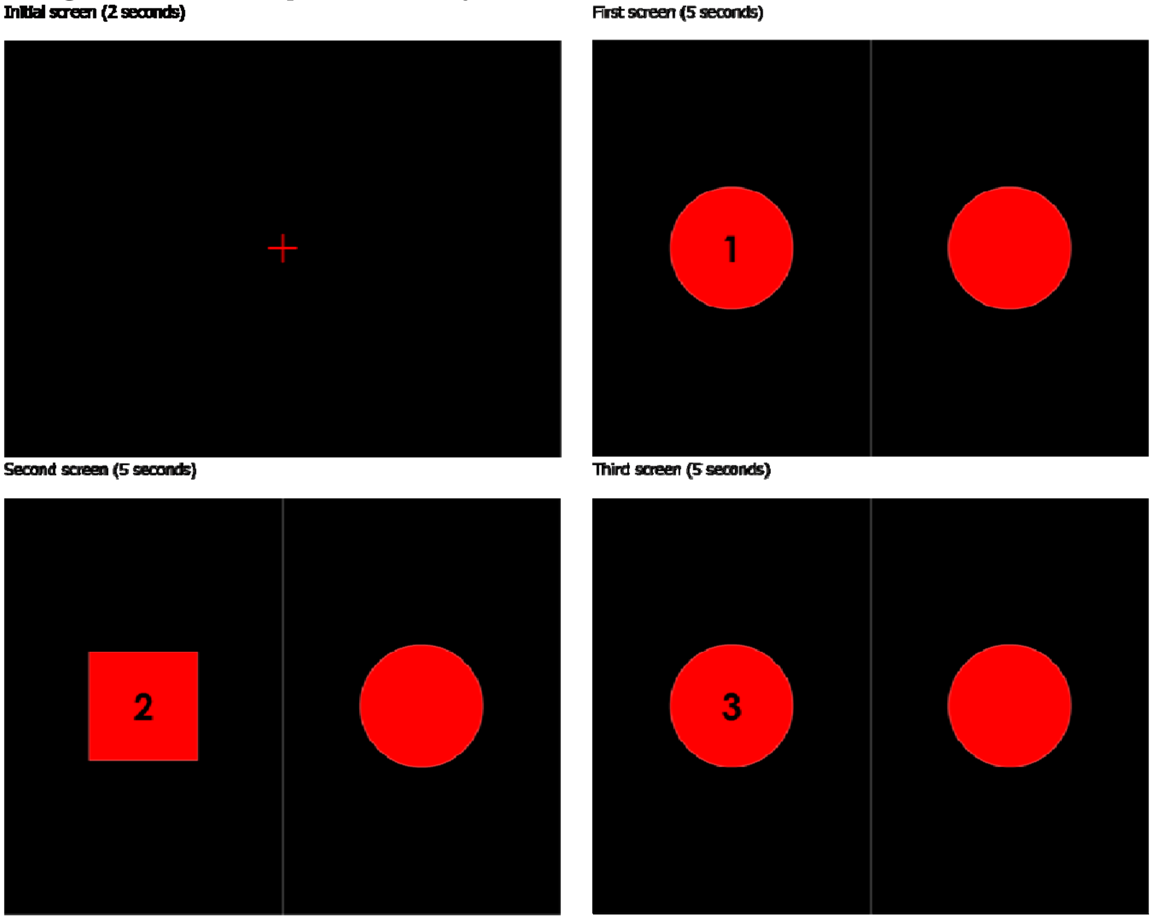
Then the nine subjects were arranged in a pre-specified order and asked to predict what was the small envelope placed in the larger opaque one with a monetary reward for each correct. To take this decision, each subject observed:

1) an independently drawn and private signal (PD), which had a two-thirds chance of indicating the correct event;
2) the former choices (FC) made by the subjects choosing previously.

The private signals were determined by a dice roll, whose possible outcomes were associated to the three cards contained in the larger opaque envelope.

To monitor gaze direction, private signals and formers choices were shown in a screen divided in two parts. An example is shown in Figure 1 that exhibits the four screens seen by the subject who chose as fourth in Session 3. In each trial, subjects were to make a saccade from the centre of the screen either toward the left or the right side of the screen and to decide what to look at. In this example, private signal was shown in the right side of the screen and former choices were shown in the left side of the screen from the first to the last. As detailed in Table 1, items shown in the screen were reversed in sessions 4-6, in which private signal was shown in the left side and previous choices in the right side of the screen to check if the left-right orientation of reading could have some systematic effect on gaze direction. An example of screen sequence is shown in Figure 1.

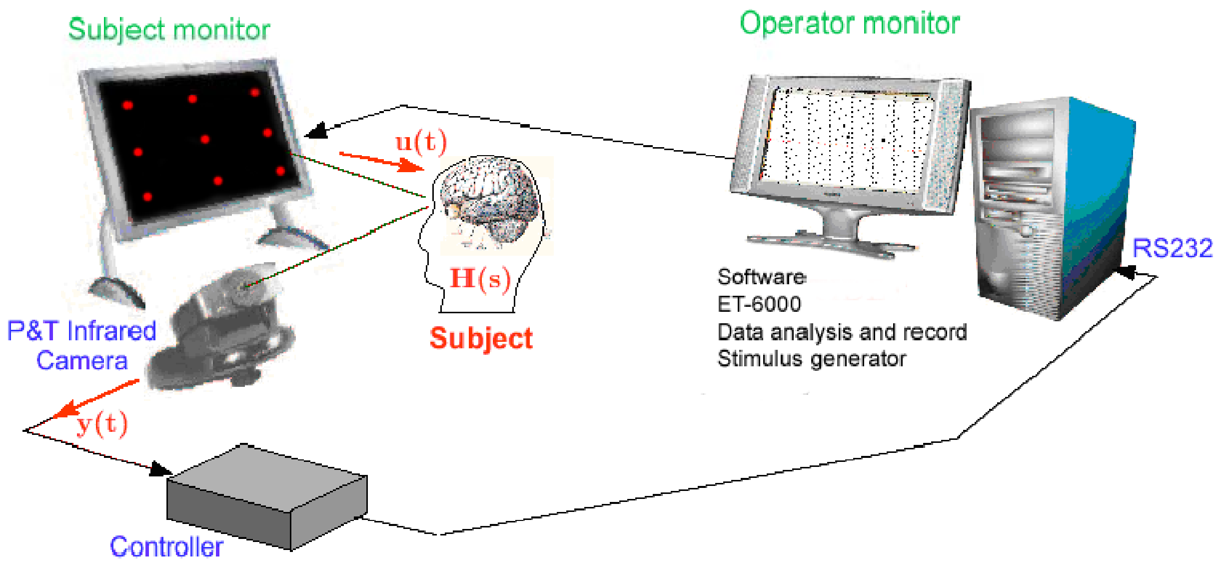
Figure 1 Screen sequence for Player 4 in Session 3



In this example, circle was the private draw and circle, square, circle was the sequence of predictions made by the first three decision makers.

Subjects' predictions were asked just after the last screen was shown. As indicated in Figure 1, the fixing cross was shown for 2 seconds and each following screen for 5 seconds. Eye movements were recorded using an Applied Science Laboratories (ASL) model 504 high-speed remote infrared eye-tracker with an ASL 5000 series controller, which samples eye position at 240 HZ, provided by the Department of Neurology of the Siena Hospital and data were processed by means of the software ET-6000 (Figure 2) . All images were presented on a 19-inch View Sonic CRT screen at 1152x864-pixel resolution. The viewing distance was always 57 cm, and each stimulus (two faces side by side) had an overall size of 30 (H) x 15(V) degrees of visual angle.

Figure 2. Experimental setting



The guidelines of the University of Siena Standing Committee on Laboratory Experiments were followed throughout the experiments. Committee and informed written consent from participants were obtained.

3. Results and Discussion

Our main experimental purpose was to investigate if subjects' patterns of choices, and eventually cognitive biases, were in some way related to gaze activity. On the basis of previous experimental evidence, in this experimental setting we expected to observe three different typologies of decision makers:

1) *Bayesian* subject, who predicts the event obtaining the greatest number of observed and inferred signal (previous choices) as implied by the symmetric distribution of the signals;

if subjects chose differently from what implied by (1), other two typologies were possible:

2) *Overconfident* subject, who predicts the event implied by her/his private signal, or

3) *Irrational* subject, who predicts the event not implied by her/his private signal.

The distribution of types we actually obtained by order of choice is shown in Table 2.

Table 2. Subjects' types by order of choice

Order of choice	Bayesian	Overconfident	Irrational
1st	6	0	3
2nd	9	0	0
3rd	5	2	2
4th	6	2	1
5th	7	1	1
6th	6	2	1
7th	6	3	0
8th	6	3	0
9th	6	3	0
Total	57	16	8
Total (first chooser excluded)	51	16	5

By discarding the first choosers, who observed only the private signal, Bayesian subjects were 51 over 72 (70%), and overconfident subjects were 16 (22%). Among the 8 irrational types, 3 chose against their private own signal as first choosers. We did not find any systematic correlation between subjects' types and screen presentation orientation (left-right vs. right-left sessions) as shown in Table 4 below.

Gaze direction was first analyzed by taking into consideration reaction times and first fixations. Fixations were defined as gazing at region of interest that was the whole half of the screen, for at least 200 microseconds.

The findings concerning the initial allocation of attention are shown in Table 3.

Table 3. Initial allocation of attention (first choosers excluded)

	Time elapsed before first fixation (seconds)	Private Draw (PD)		Former choices (FC)		Average duration (seconds)
		N. of first fixations	%	N. of first fixations	%	
Bayesian	0.306	27	52.9	24	47.1	0.838
Overconfident	0.412	13	81.2	3	18.8	0.523
Irrational	0.191	3	60.0	2	40.0	0.835
Total	0.297	43	46.8	29	53.2	0.775

The most evident finding is that overconfident subjects allocated their initial attention to private draw in 81% of the cases. Initial allocation of attention was more balanced both for Bayesian subjects (53% vs. 47%) and for irrational subjects (60% vs. 40%). The difference between overconfident subjects and the other two types is statistically significant ($t=2.0193$ $p=0.0236$).

Data also revealed another interesting pattern: overconfident subjects exhibited a longer average reaction time (0.412 sec.) and a shorter average duration of first fixation (0.532) than other types. Both differences are statistically significant: t = 2.7608 p = 0.0053 for the time elapsed before first fixation, t = 2.4013 p = 0.0096 for the average duration of the first fixation.

Table 4 shows the number of first fixations arranged by screen orientation.

Table 4. First fixation by screen sides (first choosers excluded)

	Private Draw (PD)						Former Choices (FC)					
	Left			Right			Left			Right		
	N.	Tot.	%	N.	Tot.	%	N.	Tot.	%	N.	Tot.	%
Bayesian	8	14	57.1	20	30	66.6	16	38	42.1	6	16	37.5
Overconfident	5	9	55.6	9	15	60.0	2	6	33.3	1	3	33.3
Irrational	1	1	100	2	3	66.6	2	4	50.0	0	3	0
Total	14	24	58.3	31	48	64.6	21	48	43.7	8	24	33.3

No significant difference in the pattern of first fixations across subjects' types between left and right orientation of the screen was detected. In particular, overconfident subjects looked at private draws 5 times over 9 (56%) when private draw was shown in the left side of the screen, and 9 over 15 (60%) when private draw was shown in the right side of the screen.

In the following Table 5, the total allocation of attention in percentage of total time and by screen side is shown. To compare the attention devoted to former choices and private draw, it is necessary to consider the ratio between the total time allocated to former choices and the numbers of former choices looked at. This ratio is shown in the last column that has to be compared with the percentage of time allocated to private draw, which is shown in the first column.

Table 5. Total allocation of attention (percentage of total time)

	Private Draw (PD)	Former Choices (FC)	No fixation	Total	Former Choices/ n. of former choices
Bayesian	26.9	63.0	10.1	100	22.4
Overconfident	10.4	86.4	3.2	100	19.5
Irrational	47.1	39.9	13.0	100	22.6
Total	25.6	65.3	9.1	100	21.8

Data show that during the whole time of visual investigation, irrational subjects look more at private draw (47.1%) than at former choices (22.6%). The other types exhibit a more balanced total allocation of attention. Bayesian subjects look slightly more at private draw (26.9%) than at former choices (22.4%), while the opposite is true for overconfident subjects (10.4% vs. 19.5%), but both these differences were not statistically significant (p=0.97 and p. 0.71).

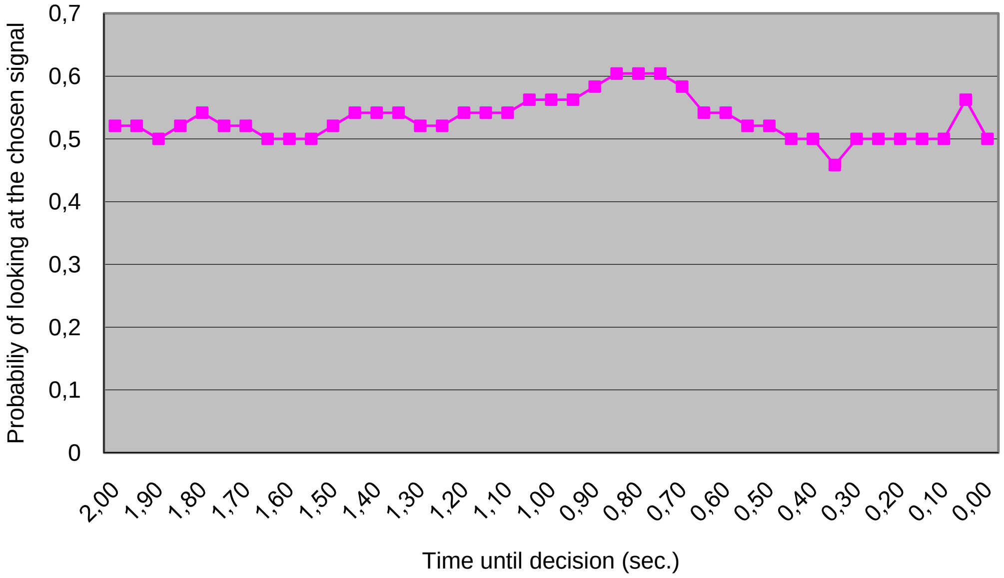
Similarly to first fixation, also for total allocation attention no relevant difference between left and right orientation of the screen side was detected, as shown in Table 6 below.

Table 6. Total allocation of attention by screen side (percentage of total time)

	Private Draw			Former Choices / n. of former choices		
	Left side	Right side	Total	Left side	Right side	Total
Bayesian	19.5	29.5	26.9	25.5	21.2	22.4
Overconfident	9.2	10.9	10.4	16.8	20.7	19.5
Irrational	52.0	12.7	47.1	21.4	27.5	22.6
Total			25.6			21.8

Finally, we collected evidence on the likelihood that subjects gaze at the eventually chosen signal measured in the last 2 seconds (Figure 1) to detect if subjects exhibited the tendency to look increasingly towards the chosen event, as postulated by the gaze cascade effect (Shimojo et al. 2003).

Fig. 3 Likelihood that subjects look at the chosen signal



Data do not provide support to the hypothesis that observers' gaze is directed towards the chosen signal. On average, there was a slight increase at 0.7 seconds before choice but this bias disappears in the final seconds. Likelihood at the final time was slightly below that of 2 seconds before.

By summarizing our finding, we provide evidence that there is significant statistical correlation between subjects' first fixation and subjects' revealed pattern of choices. Overconfident subjects look initially at their private signal, although the subsequent allocation of attention time between private draw and former choices is balanced. Bayesian subjects direct their initial attention to both kinds of information without exhibiting any particular bias. This finding can be interpreted as evidence for being automatic detection dependent on cognitive bias. Overconfident subjects exhibit patterns of initial gaze direction seemingly dependent on cognitive processes part of System 1, which are activated immediately and often unconsciously by external stimuli. Bayesian subjects did not exhibit the same kind of reaction and their profile of attention seems more dependent on the activity of System 2. The fact that gaze cascade effect is not confirmed would give further support to this interpretation.

Our experimental findings show that gaze direction is unconsciously driven but it is not out of subjects' control. As pointed out for example by Zajonc (1980), inclination or preferences are not necessarily based on cognitive processes but often precede them and affect doesn't require extensive cognitive processing to occur. The concept of perceptual fluency has been proposed to define conditions in which exposure to a stimulus creates a feature-based representation of a stimulus that allow encoding and processing of the stimulus when viewed at a later time. In our case, perceptual fluency is related to information processing in decisions under uncertainty and not to preferences but it will influence subjects' choices that are dependent on the features of a stimulus. One consequence is that perceptual fluency is based on cognitive biases in a way that is not unconsciously determined. Although this conclusion should be taken with prudence, it implies that, from a pragmatic point of view, the more these information collecting processes are driven by unconscious processes, the less a decision maker would be able to avoid the influences of incidental exposure.

As general implications, this experimental evidence contradicts views of the brain as a collection of sequential modules, starting with sensation, through perceptual integration and cognitive association to emotional valence, decision making, motor preparation and motor response Instead, it supports views which assume a multitude of parallel modules heavily interconnected and exercising influences on each other from very early on in information processing

4. **Concluding Remarks**

We collected experimental evidence supporting the view that information collection and decision processes are related to somatic-based behaviors, such as gaze orienting. Initial gaze direction is related to cognitive biases in a way that is not necessarily consistent with efficient information processing. In particular, we find that there is significant statistical correlation between subjects' first fixation and their revealed pattern of choices. Overconfident subjects look initially at their private signal, although the total allocation of attention time between private draw and previous choices is balanced. Bayesian subjects allocate their initial attention to both kinds of information without exhibiting any particular bias. Moreover, overconfident subjects exhibit reaction times significantly longer than Bayesian subjects. Finally, we did not find statistically significant evidence supporting the gaze cascade effect: observers' gaze was not increasingly directed towards the chosen signal.

Our results support the hypothesis that both controlled search and automatic detection concur to the activities of information collecting and processing. This dualism is not necessarily implemented in a synchronic way. Cognitive biases can increase such problem. In the case of overconfident subjects, gaze behavior could be determined by a cognitive construct based on past experiences. This construct would impose to look first at the private signal and overconfident subjects would need more time than others to decide if the private signal is on the right or the left side of the screen. After the first fixation the process of visual investigation would become aware and all subjects' typologies would distribute equally their attention.

More generally, we claim that information collection is not independent of implicit, non voluntary mechanisms that can be classified as part of System 1. First fixation can be considered as an output of System 1 because it is fast, unconscious and effortless and reveals what is the automatic answer of the brain for information collecting. Sequence of later fixations can be considered as an output of System 2: they are slow, effortful and deliberately controlled.

We intend to take this question further and to investigate in the future how brain activity is related to gaze direction during the process of information collecting.

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LABSI EXPERIMENTAL ECONOMICS LABORATORY
UNIVERSITY OF SIENA
PIAZZA S. FRANCESCO, 7 53100 SIENA (ITALY)
http://www.labsi.org labsi@unisi.it