Search Strategies in Simulated Traffical Situations Investigated with a Stationary Eyemarker Equipment.

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Road users' search strategies on slides of real traffical situations were investigated with a stationary device called the "Eye- Catcher" developed by Risø National Laboratory, Denmark (Hansen, 1990; Hansen, Andersen & Roed, 1995). The slides revealed road direction signs in "natural" settings and turn-left situations in crossroads, imposing a conflict situation between car drivers and cyclists.

The aim concerned the usefulness of the "Eye-Catcher" as it was implemented in the interactive exhibition at "Experimentarium", a science museum in Copenhagen, the applicated software, and more concretely to investigate search strategies on "complex pictures" i.e. slides of traffical situations. The project was initiated and financed by The Danish Road Directory.

Car drivers' scanning of direction signs was chosen as a theme for the concrete project. Aims and problems were as follows:

- How is the scanning pattern of roads users influenced by the number of information units on a directional sign table or on a system of directional sign tables.
- How and to what extent are route numbers and symbols used in the road users' scanning pattern.
- To what extent is the road user distracted by interfering bill boards, and what is the impact on reaction time and typical scanning patterns.

It is a further aim of the project to be able to organize directional signs and their environment so that they will serve road direction service as well as traffic safety in an optimal way.

Furthermore an investigation of car drivers' orienting behaviour to cyclists, during left-turning situations, was planned on a minor number of signs. The aim was to explore how car drivers scan the scene for other road users, especially vulnerable road users like cyclists, whether they observe cyclists if there are other cars in the visual field, and whether their behavioural choice reflect the observation of the cyclist.

Theoretical references

Agg (1994) investigated direction sign overload in laboratory experiments. The subjects were instructed to "follow a truck in the inner lane". On slides road directional signs were projected so that they seemed placed in the left side of the road (left hand driving). Furthermore they were instructed to localize a given destination on the direction sign and react by pointing out the direction, one should drive to reach the destination. Reaction time and choice of direction were registered. Eye movements were not redorded. She

found a complex relationship between an impact of number of destinations and route numbers on reaction time. Among other things : When the number of destinations exceed six, the mean reaction time for tables with three route numbers will exceed the reaction time of tables without route numbers. On the whole, she finds an effect of numbers of information units including: Destinations, route numbers and symbols (together with other specific information of a table, which are not found on Danish road direction signs). Her concept of information unit is used in the present investigation in a slightly generalized form - here also including distances, appearing on Danish road direction signs.

Theeuwes (1990, 1991, 1995) characterizes an active visual search as an endogenous, top-down controlled process, where the attention is purposely (or motivationally) directed to particular features relevant for the search task. The perceptional selection is task dependent. His results contradicts the common idea that conspicuous objects automatically attract attention. These results have inspired to investigate how robust the search behaviour can be, when subjects are exposed for distractors. In his experiments Theeuwes uses stilized drawings as stimuli. Eye movements are recorded.

Luoma (1984 a, 1984 b, 1988, 1989) has investigated, whether bill boards influence car drivers' eye movements and perception of road signs. In several experiments subjects were not given specific search tasks, but asked to drive and observe as normal during their driving. After certain intervals they were asked what they had observed. Among other things he found, that when a road sign and an advertising bill board are within the same visual field, the perception of the road sign is disturbed. The kind of orienting behaviour Luoma's subjects reveal, might - to a greater extent - be characterized as bottom-up or data driven - concerning the perception of the road signs - in this investigation called "attentional strategy".

Hagenzieker (1992), from whom inspiration for this research project's design was derived, recommended supplementing the eye movement data with other dependent variables. As an indirect attempt to fulfill this recommendation, the subject is in the present investigation requested to identify a specific target.

Generally, distinguishing between general and local scanpaths (Groner, 1988; Zangenmeister, Sherman & Stark, 1995) has seemed more relevant. Never the less, it hasn't been technically possible to apply the necessary methods of registration and analysis to this context. The scan path research, however, has been an inspiration in the search for more global search strategies through other means.

Slides of "natural" road table environments and traffical situations of conflicts in road crossings were used in the present experiment. The subjects were provided with instructions to identify a target through selective search on relatively "complex" pictures. Hence, finding comparative settings in the available literature has been difficult.

Equipment and methods

The guests of the science museum voluntarily served as subjects in this experiment - in the role of "one-and-for-all-subjects" (each subject one trial).

The setting was like this: The subject is seated at an adjustable chair and her head situated in a goggle-like support. The subject is instructed by continuous text based menus on a large screen, of the same size as the slide projection screen. The automatic calibration process is conducted by an interactive instruction to follow some fixation points as they appear on the screen. Provided the calibration comes off, the subject is guided through some optional tasks. The subject is able to respond visually by fixating a so-called "eye-con", which is activated after a certain fixation time. In this manner the subject visually can reply to questions concerning age, sex, driving experience, and preferred means of transportation.

A search instruction is subsequently presented on a separate screen picture. Generally the subjects are told to imagine themselves sitting behind the wheel in a car. At the road sign pictures they are instructed to find a certain destination, and at the crossroads pictures requested to turn left as soon as possible. The slide is then projected and the subject's subsequent eye movements wil be recorded. Provided the subject fixates the target area (on the road sign pictures) or the respond squares (on the crossroads pictures) the projection is stopped. And if the subject does not find the target, the projection is terminated after 10 seconds. Immediately after the projection as feed-back, the subject was shown the recorded eye movement depicted on a photo-CD copy of the slide.

The supporting software manages registration of eye positions (but not fixations), engaging a sampling frequency of 55. m.sec., and the reaction time of each task. A so-called "Report Program" shows individual eye movement patterns, superimposed on (a copy of) the inspected picture. The program works as a kind of "animation program", giving a demonstration of the eye movements in actual, half-, quart- or 1/8 the velocity of the action. The resulting eye movement pattern is then transferred and superimposed to a copy of the projected picture and subsequently imported into a worksheet program. Through this the eye movements may then enter into a qualitative documentation. Also, data can be analyzed statistically - individually and for the whole sample - in a worksheet program. This program produces matrices in 12 x 16 squares according to the positions of the eye.

The "Eye-Catcher", it is emphasized, only registers the position of the eye at the time of the actual recording. This means, that two different possible means of positions can be recorded, namely an actual fixation, i.e. when the eye is immovable, and as the eye moves at the time of recording. As such, there is no distinguishing between fixations and saccades as is usually the case. Most fixations last 100-350 m.sec., thus all fixations are recorded during the sampling sequence (every 55 m. sec.). Thus, the distinction between fixations and saccades apparently has no great significance in the present case.

The number of destinations, occurrence of route numbers, symbols and distractors (roadside bill boards) on the road sign pictures are systematically varied in a factorial design. On the crossroads pictures 6 variants appear, of which 4 are recorded "live" and two are with instructed actors.

Method

A driver searching a road sign almost always has a specific purpose in doing so; often the purpose is to find a destination (e.g. "Roskilde"). In order to simulate such orienting behaviour, the subject is exposed to searching tasks that evokes a similar act using the exposed image. In the initial instruction he's guided towards a certain target in the picture, which may be a name of a town on a road direction sign. Having found the target, the subject must fixate this for a moment, whence the system records the answer and terminates the exposure. Supplementary information may be given, requesting that the subject searches through the route numbers, e.g. "You proceed to Roskilde by route 155" or through symbols, e.g. "You are going tired ad are looking for accomodation".

The subject is encouraged to "read" the traffic and act quickly in the crossroad pictures; "Turn left as soon as possible. Will you follow the red car and turn now ?"

During the course of an experimental series, one would typically expect the subject to develop faster reaction time as well as more efficient searching strategies. The subjects from the science museum were only exposed to one picture each, and may as such all be considered to be "novices" and the data free of learning effects. Supposedly, this characteristic trait differentiates these data from most other experimental data referred to in the literature. The design only depicts results "between subjects".

649 subjects participated in the experiments. More than half the data from the subjects were inadmissible in the quantitative analysis. They were either too poorly calibrated. or the subjects hadn't read/perceived the written instruction, thus they didn't inspect the image as instructed, merely gazing with no specific purpose of doing. The results from 276 subjects with reliable search patterns remain.

Results

Quantitative analysis of the effect of the experimental design's variables during the search time

A quantitative analysis was implemented on the road sign images' effect on the variables of the experiment's design. How does the systematic varied independent experimental variables of the design; i.e., number of destinations, presence as well as absence of route numbers, symbols and distracting elements, influence the only dependable variable, i.e. the search time ? Presumably, the more destinations and information contained within a road

sign environment, the longer the search time. Further, it is presumed that the presence of route numbers, symbols and distractors will prolong the search time.
The results were analyzed - mainly by using t-tests.
Initially, the effect on the number of destinations is analyzed:

t-tests for Independent Samples of DESTINA number of destinations

Variable	Number of Cases	Mean	SD	SE of Mean
Reaction time in seconds				
DESTINA >= 7	105	**3,2476**	2,307	,225
DESTINA < 7	171	**2,5731**	2,174	,166

Mean Difference = ,6745

Levene's Test for Equality of Variances: F= ,700 P= ,404

t-test for Equality of Means					95%
Variances	t-value	df	2-Tail Sig	SE of Diff	CI for Diff
Equal	2,44	274	**,015**	,276	(,131; 1,218)
Unequal	2,41	210,15	,017	,280	(,123; 1,226)

The cutpoint between the two distributions has been set at >= 7 destinations, which splits the sample in approximately equal parts. If the number of destinations equals or is larger than 7, the average search time augments with 674 m. sec. The result is significant. As the hypothesis is one-tailed, i.e., the more destinations, the longer the search time, this contributes further to the high significance of the result (one-tailed p = 0,008).

Although an observed small effect of 79 m.sec. on the occurance of route numbers in the sign environment is indicated, this isn't significant (one-tailed p = 0,38).

An average increase of reaction time of 840 m.sec. is seen in the presence of symbols, indicating high significance (one-tailed p = 0,001).

As an attempt at a joint expression of the attentional strain, each image were graded concerning the total number of information of the road signs. The count/grading included all the following elements: destinations, route numbers, symbols and indications of distance. Information in the depicted images varies between 3 and 26. Splitting the sample in the value area by 13 elements of information, there is a difference of 679 m.sec. (one-tailed p = 0,002). Splitting the sample in approximately equally sized groups of subjects - 16 elements of information -, there is a difference of 1000 m.sec. (two-sided p = 0,000). Thus, the hypothesis of the larger amount of information contained within a road sign environment, the longer the search time is confirmed. Prolonged reaction time may be interpreted as an expression of proliferated cognitive load.

Surprisingly , there is no indication of the effect in the presence of distractors, operationalized as bill boards. Actually, the effect is negative, since the presence of a distracting element reduces the reaction time with 128 m.sec.; a difference that none the less isn't significant (one-tailed p = 0,32). The explanation may be, that many other circumstances apart from the operationalized distracting element might have a distracting influence, and that the depicted situations may be so diversified, that there is little sense in comparing the influence of distracting element across the situations.

Fortunately, within the sample there are ways to scrutinize this paradox at closer range. Two of the depicted pictures are identical except for a distracting element (a bill board), superimposed in its "twin-image" by photo manipulation. An other pair of images, both depicting the same crossroad from slightly different angles, though one contains a distracting bill board of a local flea market. Instructions to each twin-picture pair is evidently identical. These 6 pictures were thus analyzed apart in reference to a possible distractional influence. The effect turned out to be exceedingly significant, namely 1417 m.sec., or more than the double search time on images with distracting elements (one-tailed p = 0,003).

Hence it is concluded that on dias depicting actual complex road sign environments has been possible through a systematically varied design to indicate significant search time effects on numbers of destinations, of presence of symbols and of collected elements of information (numbers of information), but not on presence of route numbers. Influence of distractors hasn't been generally demonstrated, except through a separate analysis of images of identical tasks and depicting identical versus approximately identical situations.

Qualitative categorizing as well as qualitative and quantitative analysis of patterns of eye movement.

The individual data has been categorized "manually" in a qualitative manner according to a series of categories of which the following 7 will be noted henceforth: status (OK, possibly adequate, dispensable), calibration (OK, somewhat "awry" but interpretable, dispensable), number of times selected image elements were looked at, number of times the experimentally induced distractor was looked at, number of times naturally occurring distractors were looked at, characteristic pattern of eye movement, and whether the task was completed correctly/falsely.
The term "looked at" refers to the outcome of the following "manual" categorizing procedure: On every test image a number (6-7) of the image's most significant or prominent features/areas are identified and numbered. One of these areas is the target area, that the observer will be requested to find and fixate on. Others may be distractors, another part of the road sign, an approaching vehicle traveling in the opposite direction, etc. During the slowest section of the animation speed in the "Report-program" (1/8 of the actual speed of eye movement), there is manually registration of the position of the gaze in a numbered area of the image. As the gaze is directed outside of this square and then redirected into it, another registration takes place of the "gaze", and when directed into another area of the

image, this too is recorded according to the number of the new square. It hasn't been possible to record the duration of time of the gaze.
This procedure is exceedingly time consuming, so that only 2 roads sign- and 2 crossroads images were analyzed. Data from 74 test subjects were processed. Only data where status and calibration is OK were included in the analysis, and all the "attention profiles" - that is, subjects who didn't fixate the target - were discarded.
Identification of three different search patterns was successful, described this way:
1. **Direct** - in which the test subject moves the eyes directly from the point of departure towards the goal,
2. **There-and-back** - the attention pattern here is simple as well, though contrary to the direct pattern the round-trip involves a single regression.
3. **Star** - describes a more complex pattern, in which the picture elements are searched and often re-checked in various successions. Sometimes the star shaped pattern may be seen in attention scans as well.
4. **The Merry-Go-Round** - signifies a tour among all the prominent elements of the image, sometimes repeatedly, typically aimlessly. Thus, the Merry-Go-Round pattern has been characterized as an attention pattern.
It is extraordinary - albeit perhaps trite - that an eye movement pattern may be identified as respectively a search pattern versus an attention pattern exclusively on the basis of its shape. Even without the researcher's knowledge of the task instruction.
Notably, as yet the above mentioned descriptive categories cannot completely be distinguished on their own. Especially problematic is the unambiguous distinction between the star and the Merry-Go-Round patterns, as signified by the frequency table below: Two subjects have used a Merry-Go-Round pattern, but their orientation behaviour has been recorded as search strategy.
Pattern characteristic on two road signs and two crossroads images:

Value Label	Value	Frequency	Percent	Percent	Percent
Merry-Go-Round	1,00	2	2,7	2,7	2,7
Star	2,00	40	54,8	54,8	57,5
There-and-back	3,00	15	20,5	20,5	78,1
Direct	4,00	16	21,9	21,9	100,0
	Total	73	100,0	100,0	

Half of the subjects uses a star-shaped scanning pattern, app. 20 % the there-and-back pattern, app. 21 % the direct pattern, while only 2 test subjects or 3 % uses the Merry-Go-Round pattern.

The two road sign pictures:

On the road sign images there is a slightly different distribution of search patterns. as 1/3 use a star pattern. barely 40 % use the there-and-back pattern, a little over 1/5 use the direct pattern, - signifying a tendency towards a simpler search pattern.
A clear effect of the search pattern on "number of fixations" (i.e. number of times the gaze was directed towards a square) appears, in that the star and the Merry-Go-Round employs

just short of 5 fixations more than - i.e., more than the double amount as - the direct and the there-and-back patterns. The result is highly significant (one-tailed p = 0,001).
The search time, too, was affected by the search patterns. The star and the Merry-Go-Round pattern takes 3184 m.sec. longer - i.e., 3 times as long - than the there-and-back and the direct pattern (one-tailed p = 0,001).

The two crossroads pictures:

The dominating search pattern on the crossroads pictures was the star (app. 71%), close to 20 % uses the direct, while 7 % employs the there-and-back pattern. No Merry-Go-Round pattern was recorded. A tendency towards a predominantly more complex search patter was found in this case.
Almost 6 fixations marking the difference - i.e., app. 2,5 times as many - being employed within the star pattern, as opposed to the amount used on the there-and-back and the direct pattern. The result is highly significant (p = 0,000).
The star pattern takes 2950 m.sec. more than - i.e., more than the double amount of time - the there-and-back and the direct pattern (p = 0,000).

Summary on patterns of road signs- and crossroads pictures:

As far as the road sign pictures is concerned, the search behaviour is characterized by relatively fewer fixations (6,53) and briefer time spans (2530 m.sec.), as opposed to 7,9 fixations and 4520 m.sec. on crossroads pictures. The text bar on the crossroads pictures is no doubt a contributing cause to a large proportion of this difference, but there is further evidence indicating, that the crossroads tasks were more difficult to complete.
In both counts the number of fixations when taken as one was 2-2,5 times as big.
Likewise, the search time was 2-3 times as long on the star and the Merry-Go-Round compared to the there-and-back and the direct patterns.

When the sample is divided in two almost equal parts (7 fixations), the search time escalates 2,5 times or at a mean of 2145 m.sec. (p = 0, 000).

The correlation between number of fixations and search time is relatively invariant across several tasks and contexts. The possible interpretation of this is, that typically the driver employs a brief inspection of one or more of the picture's elements, possibly repeatedly, instead of a more thorough inspection of each element separately. The discovery that when increasing the number of times the subject looks at the squares of the picture, the search time is likewise increased may seem banal. But prior to the investigation, this was by no means evident. The subject might carefully have examined each element of the picture separately.

Looked at, but not perceived.

Working with the material, it has been possible to identify situations, where the subjects has "looked at, but not seen" one or more necessary objects in order to complete the task.

The interpretation of whether the subject had "looked at, but not perceived" is actually facilitated through the introduction of a conflict between some of the elements in the instruction, e.g. between the wish to make an immediate left turn and the desire to let an approaching, not very visible weak road user traveling in the opposite direction pass.

It is (maybe) permissible to conclude in case of a correctly solved task, that the subject has "looked and perceived" when in fact the eye has been fixated on the "target object", and " not looked at, but perceived" in the case where the subject didn't fixate the target object. In case of a false answer in may be concluded, though, that the subject has "looked at, but not perceived", when the target object has been fixated, and "not looked at and not perceived", when the target object hasn't been fixated.

The amount of material analyzed so far is, however, so small, that statistical adaptation is inadmissible. Qualitatively, though, the following example may be given:

The instruction for this picture is: "Turn left as soon as possible. Do you want to turn now?" As seen, the text bar contains a resume of the instruction: "I turn immediately, as soon as the white cars have turned away". The critical detail - the target - is a cyclist, situated directly behind the right-turning car.

The subject employs a star-shaped search pattern. Initiating, he scans the text bar briefly, then the approaching left-turning car traveling in the opposite direction, proceeds oscillating a few times between the target (the cyclist) and the right-turning approaching car traveling in the opposite direction, a single detour to the approaching left-turning car, also traveling in opposite direction, and then finishing off by reading the text bar and choosing the answering space by "yes".

In advance the answer is categorized as false, because there is imminent danger of collision with the approaching cyclist. Despite the subject's thorough inspection of all relevant elements, he chose an incorrect solution. This action may be interpreted as an example of "looked at, but not perceived".

Alternatively, it may be argued whether the subject hasn't perceived the risk of conflict, expects the cyclist may keep back, etc.

Discussion

Method: The "Eye-Catcher" having been placed as an element of entertainment at a science museum has been problematic. In part because the calibration appeared to be extremely vulnerable. Only data from 20% of the persons who attempted to use the "Eye-Catcher" was recorded. Among those who passed the automatic calibration task successfully, some weren't able to sit absolutely still during the preceding process, so that their data was rejected or this at least provided strenuous interpretation of these data. Furthermore, a number of subjects had "overlooked" the written instruction, and in doing so, didn't know which task to complete, when the picture was exposed. As previously mentioned, their data are categorized as "attention strategies". All in all, this signifies a vast loss of data.

Despite these reservations, never the less reliable data from 276 subjects remain. These data are remarkable at least in respect of two aspects: First, they have no underlying learning effects. On one hand, this complicates the comparison of these data to other reported data. On the other hand, one might appreciate that this unites these data in a sort of virginal as well as unsophisticated state, which is commendable. An additional trait is that through their comparison to other collected data, more universal traits of search strategies are revealed. Possibly the most remarkable finding is, that a design producing purely "between subjects" data reveals discoveries of a more general nature.

Primarily, the more global traits are here considered to be:

- That the elements in the pictures are typically focused on several times at short velocity instead of being scrutinized thoroughly element by subsequent element.
- That great individual differences in search strategies appears.
- That the search strategies through great approximation simply on the basis of their shapes may be distinguished from attentional strategies.
- That the effects of cognitive strain is detected in such diversified and complex images (despite the vast difference in the contexts of the images) in the form of number of information units
- And even more notable; that single parameters such as number of destinations and prevalence of symbols is manifest.

Contrary, it seems there is no instances in support for noting the absolute reaction time.

At a more general level of abstraction, one might possibly indicate the parallels between top-down directed, endogeneously controlled visual selection, the global scanpaths and the presently caraterized patterns of orientation: The direct, the Merry-Go-Round and the star search patterns - as well as the bottom-up directed, exogenously controlled local scanpaths and the Merry-Go-Round attentional pattern presently introduced.

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