The Influence of Cognitive Load and Amount of Stimuli on Entropy through Eye tracking measures

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Abstract

Entropy can be described qualitatively as a measure of energy dispersal. The concept itself is linked to disorder: entropy is a measure of disorder, and nature tends toward maximum entropy for any isolated system. One of the fields in which energy dispersal can be quantified is eye scanning in visual search. It is well known that visual research time in eye scanning is influenced by the number of targets to explore: the higher the number of targets, the longer the exploration time. The aim of this study is to understand whether the exploration time on non target stimuli depends on cognitive load and on the number of distracting stimuli. 26 voluntary students (mean age and standard deviation: 23.53 and 3.2) were involved in the study. Eye-Tracker technology was used with an intuitive and accessible graphic interface. The subjects were asked to detect and look at a target, as quickly as possible. During this task, in the first study subjects were also asked to listen to and repeat a list of numbers read aloud by an experimenter. In the second study distracting stimuli were manipulated by increasing their number. Results showed that both the amount of cognitive load and the number of distracting stimuli increase the entropy of eye movement. Results are discussed in terms of entropy theories.

Keywords: entropy; eye tracking; top down processes, cognitive load; bottom up elaboration;

Introduction

The term "entropy" comes from the Greek εντροπία "a turning toward, from εν- "in" + τροπή "a turning", and is a measure of the unavailability of a system's energy to do work. From an evolutionary perspective, the fundamental goal of a nervous system is to integrate appropriate perceptual frames and behavioral responses with the steady flow of sensory information, so that biological needs can be adequately satisfied (Swanson, 2003). Consequently, there are two primary domains of uncertainty that must be contended with from a psychological perspective: uncertainty about perception and uncertainty about action (Hirsh, Mar, & Peterson, 2012).

In psychology, researchers have used entropy to measure basic cognitive limits (Miller's [1956] magical number seven plus or minus two) and, as a stimulus property, to predict aesthetic preferences (Berlyne, 1974b). Another field in which energy dispersal can be quantified is visual scanning related to eye movement. Wang et al. (2010) propose a biology-inspired bottom-up computational model of attention based on visual salience. The authors propose a new visual scanning measure derived from the principle of information maximization. This principle suggests that the human visual system (HVS) tends to focus on the most informative points on an image in order to efficiently analyze the scene. They simulate the computational function of visual saliency in the brain in which the saliency is defined as Site Entropy Rate (SER) based on the principle of information maximization. The experiments demonstrate that the proposed model achieves the state-of-art performance of saliency detection.

The basic assumption of eye movement is that the observer's attention is usually held only by certain elements of the picture, and so eye movements reflect human thought processes; so the observer's thought may be followed to some extent by recording eye movements (the thought accompanying the examination of the particular object). From these records it is easy to determine "which elements attract the observer's eye (and, consequently, his thought), in what order, and how often" (Yarbus, 1967). In 1980, Just and Carpenter formulated the influential Strong eye-mind Hypothesis, the hypothesis that "there is no appreciable lag between what is fixated and what is processed". If this hypothesis is correct, then when a subject looks at a word or an object, he or she also thinks about it (processes it cognitively), and for exactly as long as the recorded fixation lasts. During the 1980, the eye-mind hypothesis was often questioned in the light of covert attention (Posner, 1980), that is the attention to something at which one is not looking, which people often do. If covert attention is common during eye tracking recordings, the resulting scan path and fixation patterns will often not show where our attention has been, but only where the eye has been looking, and so eye tracking will not indicate cognitive processing. According to Hoffman (1998), the current consensus is that visual attention is always slightly (100 to 250 ms) ahead of the eye. But as soon as attention moves to a new position, the eyes will want to follow (Deubel & Schneider, 1996). Based on this current consensus, in this work we use the Eye Tracker to analyze visual search.

In the view of Siemens (2009), educators need to embrace the unpredictability because randomness in codifying information can lead to deficit in learning. The problem is that all entropy decreasing-transformations can't leave any trace (e.g. in a memory) of them having happened (Maccone, 2008)

Visual search related to visual scanning randomness was related to entropy processes. Visual search is influenced by both top-down and bottom-up processes. Hirsh, Mar, & Peterson (2012) proposed a computational model of entropy mainly based on bottom-up processing.

In this study, with reference to bottom-up processes, the number of items to explore in order to find the target is important: the higher the number of targets, the longer the exploration time. With reference to top-down processes, the role of cognitive load is controversial. Some studies (e.g., Hilburn, Jorna, Byrne, & Parasuraman, 1997) report that visual scanning randomness (or entropy) is related to mental workload: high task load conditions would generate less randomness than would low task load conditions. Other studies show an opposite pattern, namely that higher entropy could be associated with higher mental workload as well (Kruizinga, Mulder, & de Waard, 2006). Other more recent studies (Camilli, Nacchia, Terenzi & Di Nocera, 2008) using spatial statistics algorithms report that when the mental workload is high, eye fixation is dispersed, while when mental workload is low, eye fixation is clustered.

In this study entropy of visual scanning was defined by: DTNT = TT – DTT, where TT is the total duration of time search and DTT is the fixation time on the target stimulus.

The rationale to measure entropy in such a way is that the amount of energy dispersal can be defined by randomness of search behavior, i.e. by the time lost to find the correct target, the time lost in coming back to distracting stimuli and the time lost in fixating the eye on one or more distracting stimuli. By using an implicit free-viewing task to search for the target, we can compare the distribution of attention across a range of tasks.

Specifically the purpose of this study is to understand whether the energy dispersal of the eye scanning (exploration time on non target stimuli, entropy) also depends on the intensity of the cognitive load and on the number of distracting stimuli.

Study 1

Method

Subjects

26 voluntary students (16 females and 10 males) attending courses at the Catholic University of the Sacred Heart of Milan. The age of the subjects was between 19 and 31 (mean and standard deviation: 23.53 and 3.2). The sample comprised normal-sighted subjects, all with visus values between 0.9, and 1 with their usual visual correction where applicable.

Task specifications

Eye-Tracker consists of an instrument that is transportable, works without further equipment and can be used in normal room light conditions. In this study, we used the model "iAble© - MyTobii®" ("D10" version), a system of ocular and vowel control. The system was composed by an eye-tracker, by a computer and related software. The graphic interface was highly intuitive and accessible, and the controls were projected according to a multimodal input (vocal and ocular command).

The interface's efficacy was validated thanks to usability's studies and "beta test" on the field, perceived primary with subjects.

The picture used for the eye tracker's first task consisted of three different complex images, in which a little yellow duck was hidden. The first image showed a kitchen, the second showed a country view, and the third represented a supermarket (for the image, see fig. 1 at the end of the paper).

The complex images used in this part of the research were divided into two groups, 5 for the first test and 3 for the second one.

Before beginning the experiment, the perceptual salience of this complex stimuli was weighted. An independent sample of 12 subjects of the same age of the study sample judged the complexity of the ten complex cards within which there were those of the fig. 1; the judgment ranged from 1 (not complex) to 10 (very complex). The results of the evaluation of the three final complex stimuli were very similar. The means were 7.2, 7.8, 7.1 respectively.

Procedure

The tasks of the experiment were administered during a break between ordinary lessons, in a university laboratory. The setting was a 4x5 meters room, with a table in the center; on that table the eye-tracker was placed and in front of it, at a 50 centimeters distance, sat the subject. In the room there were normal light conditions. The experimenter remained always in the room, ready to answer in case of questions. Each subject completed consent forms prior to participation in the study

Memory load was then determined for each subject using the test of digit span of the Wechsler scale, in a silent classroom. Two different tasks were then administered. In this first task, subjects were instructed to observe a target stimulus (fig. 1: “target”), a little yellow duck. Then, the subjects were asked to spot, as quickly as possible, the little yellow duck that was hidden in a complex image. At the same time, participants were asked to listen to and repeat a list of numbers read aloud by an experimenter. Memory load was in fact manipulated by increasing or decreasing the memory set, thanks to three different conditions:

−visual scanning without any cognitive interference due to other simultaneous tasks (no load = 0 digits);

−visual scanning with a contemporaneous second task that involved half of the cognitive subject’s load (half load = (span-1)/2 digits);

−visual scanning with a contemporaneous second task that involved the entire subject’s cognitive load (full load = span -1 digits).

Every complex image was presented for 90 seconds. The total length of the second working session was about 10 minutes. The slide’s sequence was the following:

1) Verbal instructions: “Look at this little yellow duck and try to memorize it”;

2) Presentation of the target stimulus;

3) Verbal instructions: “Try to spot, as quickly as possible, the little yellow duck that you have seen before, and stare at it until the change of the picture”;

4) Presentation of a complex image in which the target stimulus was hidden (no cognitive load);

5) Verbal instructions: “Try to spot, as quickly as possible, the little yellow duck that you have seen before, and stare at it until the change of the picture; at the same time, repeat after me the list of the numbers I’m reading to you”;

6) Presentation of a complex image in which the target stimulus was hidden (half cognitive load);

7) Presentation of a complex image in which the target stimulus was hidden (entire cognitive load);

8) Last slide in which “thank you” appears.

The whole experiment took about 40 minutes. Four measures of task performance were recorded: the time before correct fixation (DBF); the number of fixations on target stimulus (NFT); the duration of fixation time on the correct target stimulus (DTT); the duration of fixation time on the non-target stimuli (DTNT).

This last measure was obtained from: DTNT = TT – DTT, where TT is the total duration of time search and DTT is the fixation time on the target stimulus. Subjects had ninety seconds to complete each of the three tests, consisting in finding the hidden yellow duck.

Results

The visual scanning data were analyzed by comparing the time before correct fixation (DBF), the number of fixations on target stimulus (NFT), the duration of fixation time on the target stimulus (DTT), and the duration of fixation time on the non-target stimuli (DTNT). After verifying normal data distribution, analysis of variance was applied. A significance of .05 was considered.

With reference to the first parameter, the time before correct fixation (DBF), there is a significant effect on cognitive load, $F(2, 50) = 13.43$, $p < .01$. This result suggests that the higher the cognitive load, the longer the time spent to find the target for the first time. More specifically, post hoc analysis shows statistical differences between the absence of cognitive load and full load, $t(25) = 23.56$, $p < .001$ (Tab. 1).

With reference to the second parameter, the number of fixations on target stimulus (NFT), there is a significant effect on cognitive load, $F(2, 50) = 25.9$, $p < .001$. This result indicates that the higher the cognitive load, the lower the number of fixations on target stimulus. Post hoc comparisons show a significant effect between no load and half load, $t(25) = 7.288$, $p < .001$ (Tab. 2), between no load and full load, $t(25) = 18.46$, $p < .001$ (Tab. 3), and between half load and full load conditions, $t(25) = 11.179$, $p < .001$ (Tab. 1).

The same trend, with reverse results, can be observed on the parameter DTT, duration of fixation time on the target stimulus, in which there is an effect on cognitive load, $F(2, 50) = 4.32$, $p < .002$. This result indicates that the higher the cognitive load, the longer the duration of fixation. Post hoc comparisons show a significant effect between no load and full load conditions, at $(25) = 14.038$, $p < .001$ (Tab. 1).

Finally, with reference to the parameter that indicates the entropy level, DTNT = TT – DTT, there is a significant effect on cognitive load, $F(2, 50) = 25.91$, $p < .001$. This result suggests that the higher the cognitive load, the longer the total time spent in looking at non target stimuli. Post hoc comparisons show a significant effect between no load and half load, $t(25) = 7.28$, $p < .001$, between no load and full load, $t(25) = 18.46$, $p < .001$, and between half load and full load, $t(25) = 11.179$, $p < .001$ (table 1).

Table 1 Means and standard deviations (S.D) of the four parameters of eye tracking related to the cognitive load

Conditions	DBT	NFT	DTT	DTNT = TT-DTT
No load	10,666 (2,9)	31,902 (3,3)	39,962 (5,3)	28,098 (3,3)
Half load	11,106 (2,5)	24,614 (2,9)	34,231 (4,6)	35,386 (2,9)
Full load	34,231 (4,6)	13,435 (2,5)	25,923 (4,6)	46,565 (2,5)

Study 2

The aim of this second study is to analyze whether energy dispersal of eye movements is related not only to top-down factors such as cognitive load, but also to objective factors such as the number of distracting stimuli.

Method

Participants

The same 26 voluntary students in the first study were engaged.

Task specifications

The picture used for the eye tracker's second task consisted of an increasing series of little squares (0,5 x 0,5 cm) with a little segment starting from one corner, respectively the left and right corners at the top and the left and right corners at the bottom of the squares. The target stimulus was the square with the segment situated in the right corner at the top (fig. 2: "target"). All the other combinations of squares were considered distracting stimuli (fig.: 2: "target and 5, 10, 15, 20, 25 distracting stimuli").

Stimuli were presented in five different combinations, in particular with 5, 10, 15, 20, 25 distracting stimuli. Subjects had ninety seconds to complete the test, consisting in finding the correct target stimulus.

Procedure

In this second task, subjects were asked to find, as quickly as possible, the stimulus target within a series of distracting stimuli. In the first test the subjects were instructed to observe a target stimulus (fig. 2: "target"), a square with a segment starting from the upper right corner, and upper-slanting. Then they had to find the correct target they had seen before, in an image in which the target appeared with an increasing series of distracting stimuli (respectively 5, 10, 15, 20, 25 distracting stimuli). Every slide was presented for 90 seconds. The total length of the first working session was about 10 minutes. The slide's sequence was the following:

1) Verbal instructions: "Look at this little square and try to memorize it";
2) Presentation of the target stimulus for five seconds;
3) Verbal instructions: "Try to find, as quickly as possible, the little square that you have seen before, and stare at it until the change of the slide";
4) Presentation of the target stimulus with 5 distracting stimuli;
5) Presentation of the target stimulus with 10 distracting stimuli;
6) Presentation of the target stimulus with 15 distracting stimuli;
7) Presentation of the target stimulus with 20 distracting stimuli;
8) Presentation of the target stimulus with 25 distracting stimuli.

Results

The visual scanning data were analyzed by comparing the time before correct fixation (DBF), the number of fixations on target stimulus (NFT), the duration of fixation time on the target stimulus (DTT), and the duration of fixation time on the non-target stimuli (DTNT). After verifying normal data distribution, analysis of variance was applied. A significance of .05 was considered.

With reference to the first parameter, the time before correct fixation (DBF), there is a significant effect on the number of distracting stimuli, $F(4, 100) = 11.49$, $p < .01$. This result suggests that the higher the number of stimuli (from 5 to 25), the longer the time spent to find the target for the first time. With reference to the second parameter, the number of fixations on target stimulus (NFT), there is a significant effect on the number of distracting stimuli, $F(4,100) = 6.214$, $p < .014$. This result suggests that the higher the number of stimuli, the lower the number of fixations on target stimulus. The same trend, with reverse results, can be shown on the parameter DTT, duration of fixation time on the target stimulus, in which there is an effect on the number of distracting stimuli, $F(4,100) = 6.62$, $p < .01$. Those results indicate that the higher the number of stimuli, the lower the duration of fixation. Finally, with reference to the parameter DTNT, the fixation time on the non target stimulus, there is a significant effect on the number of distracting stimuli, $F(4,100) = 6.63$, $p < .01$. This result suggests that the higher the number of stimuli, the longer the fixation time on the non target stimuli. With reference to DTNT, post-hoc comparisons show a significant effect between 5 and 20 distracting stimuli, $t(25) = 4.617$, $p < .001$, and between 5 and 25 distracting stimuli, $t(25) = 4.348$, $p < .001$.

Table 2 Means and standard deviations (S.D.) of the four parameters of eye tracking related to the amount of distracting stimuli.

Number of distracting stimuli	DBT	NFT	DTT	DTNT= TT-DTT

5	1,352 (.17)	2,667 (.25)	4,346 (.58)	11,665 (3.25)
10	1,689 (.27)	2,100 (.24)	3,385 (.48)	29,00 (4.24)
15	2,478 (.25)	1,992 (.25)	4,000 (.68)	45,12 (3.25)
20	3,160 (.28)	1,370 (.24)	1,923 (.41)	72,6 (6.24)
25	3,231 (.35)	1,270 (.28)	2,115 (.52)	87,25 (3,73)

Discussion

The results of both studies indicate that energy dispersal of eye movement depends on both top-down and bottom-up factors. In this case, both the amount of cognitive load and the number of distracting stimuli influence energy dispersal.

The parameters here examined are not independent ones. They are related and DTNT derive from basic parameters: the lower the time before correct fixation (DBF), the higher the number of fixations on target stimulus (NFT), the higher the duration of fixation time on the target stimulus (DTT), and the lower the entropy (DTNT).

Cognitive load not only affects complex cognitive factors, but the analysis of the four parameters suggests that it is relevant also in visual scanning. Particularly, time "lost" or dispersed, id est time spent on search on not target stimuli, is high both on the time before correct fixation (DBF) and on the entropy level. The present results are in line with evidence from Kruizinga, Mulder, & de Waard (2006), underlying that higher entropy could be associated with higher mental workload, and with evidence from Camilli, Nacchia, Terenzi & Di Nocera (2008) that highlighted that when the mental workload is high eye fixation is dispersed, when the mental workload is low eye fixation is clustered.

In the area of research on distraction, this question is very important. From a bottom-up perspective, considerable evidence suggests that distracting stimuli can interfere by having common qualities with the target, such as color (Stroop, 1935) or orientation (Joseph & Optican, 1996). Others have looked at adjacent distracters (proximity) and their influence (Flowers & Wilcox, 1982).

To understand what causes distracters to be detrimental to task performance, eye tracker technology can be useful. Further research with eye tracker can give us information on entropy styles and on how the energy dispersal may impact the distraction and the related learning deficits.

In a task requiring more effortful attention, such as a visual search task, distracters that are processed automatically may provide more interference and enhance entropy. Another factor is that visual search tasks require more effort for attention control when distracters are randomized and unpredictable (Michael, Kiefer, & Niedeggen, 2012; Neo & Chua, 2006). Eye tracker technology can help us to visualize the eye movement and the factors that can maximize information through the clustering process that reduce entropy.

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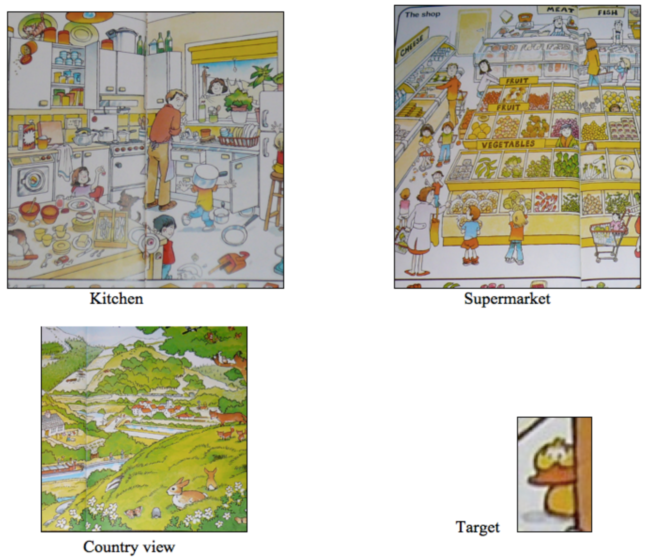

Fig. 1 Picture used for the eye tracker's first study and target

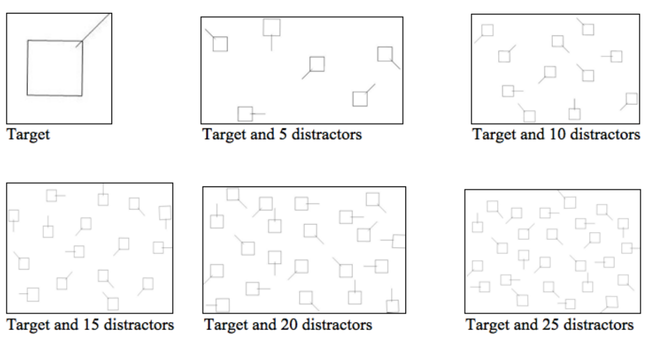

Fig. 2 Target stimulus and distracting stimuli in the five levels of complexity