UNIVERSITÀ DEGLI STUDI DI PADOVA

Sede Amministrativa: Università degli Studi di Padova

Dipartimento di Psicologia Generale

SCUOLA DI DOTTORATO DI RICERCA IN SCIENZE PSICOLOGICHE

INDIRIZZO PERCEZIONE E PSICOFISICA

CICLO XXI

INATTENTIONAL BLINDNESS:
WHEN LOOKING IS NOT ENOUGH

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CHAPTER 1

Overview

1.1 Attention

People fail to notice things all the time; at any given moment, we are bombarded with a huge amount of information from the world, more than we can take in, and it would be impossible for our cognitive system to process all this amount of data. Directing our attention to a particular stimulus, often entails ignoring other stimuli elsewhere; to remain focused on our task we need to select only relevant information for further processing. Information not receiving further processing fails to reach awareness.

Attention includes all the cognitive processes allowing us to selectively concentrate on one aspect of the environment, while ignoring others.

Our ability to process visual information is called '**visual attention'**. Visual attention includes all processes enabling a person to recruit resources for processing selected aspects of a visual scene. This definition implies two different properties of attention that theorists distinguish — capacity and selectivity.

Capacity is the amount of attentional resources available at any given moment for a task or process. It is influenced by different factors; such as motivation, alertness, and time of the day.

Selectivity concerns the amount of attention paid to different parts of visual information can be allocated flexibly to some degree. With the term **selective attention**

we refer both to the ability to select relevant information and to the ability to contrast distraction. Selective attention has been studied with the Stroop paradigm (Stroop, 1935) in which participants see a word printed in a colour differing from the colour expressed by the word's meaning. For example, the word 'red' printed in blue ink. In the incongruent condition, this task requires participants to selectively concentrate on the word's ink colour while ignoring its meaning. In this condition, naming the word's colour takes longer and is more error prone when the word's meaning and its ink colour are congruent.

Now state the colors as fast as you can				Again, state the colors as fast as you can			
Row 1	Red	Blue	Green	Yellow	Red	Blue	Green	Yellow
Row 2	Yellow	Green	Blue	Red	Yellow	Green	Blue	Red
Row 3	Green	Red	Yellow	Blue	Green	Red	Yellow	Blue

Figure 1 An example of Stroop paradigm: naming the colour of the words takes longer in the second case, when they are printed in a colour incongruent with their semantic meaning.

Voluntary eye movements are the first step of visual attentional selection. However, with some effort, eye movements and shifts of attention can be separated. This happens, for example, in experiments in which participants have to keep their eyes on a fixation point, and while monitoring a screen. This is difficult because attention and eye movements normally go together, but the possibility to separate them is evidence of the ability to pay attention to elements without fixating on them.

On the other hand, attention-shifts alone may be insufficient to bring a stimulus into awareness. Apart from some neuropsychological conditions, normal people show

evidence of some forms of dissociation between visual processing and visual awareness, as well. According to Neisser (1976), conscious perception requires a temporally extended and active engagement on the stimulus. With his '*perceptual cycle*' theory he suggested that a cyclical process of visual interpretation and reinterpretation ultimately determines our conscious percepts.

Despite our attentional system's limited capacity, we are seldom conscious of the limitations of our visual representation, in the sense that we always have the impression of seeing everything in a visual scene.

As an explanation, Rensink (2005) suggested the existence of 'just-in-time' representations in which detailed representations of objects and events are created only when requested. He suggested this system is something like light in a refrigerator — if the light is always on when needed (that is, when the door is open), it will appear as if the light is on all the time.
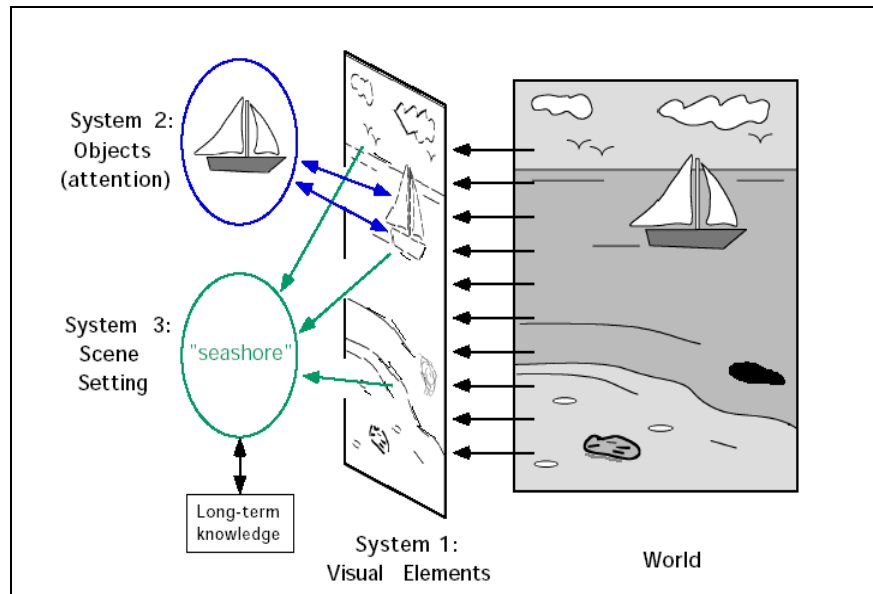
System 2:
Objects
(attention)

System 3:
Scene
Setting

"seashore"

Long-term
knowledge

System 1:
Visual Elements

World

Figure 2 'Just-in-time' scene representation. It is suggested that visual perception of scenes can be carried out via an interaction of three systems. Initially, a system analyses visual inputs and converts them into a series of simple, low-level visual elements. Then, focused visual attention acts as a hand grasping a small number of these elements. While held, these form a stable, visual representation of the object. At this level, it is possible to perceive if a change occurs. After attention releases them, these items return to their original status of simple visual elements.

Selectivity has been demonstrated also within auditory attention by the well-known 'cocktail party effect', which describes the ability to focus one's listening attention on a single talker, while ignoring other conversations. This effect also implies we can rapidly orient our attention to another stimulus if it is considered relevant. This happens, for example, when we are talking with a friend at a crowded party. We are able to selectively concentrate on what our friend is saying and ignore what a nearby person is saying. However, if someone suddenly calls our name from the other side of the room, we can notice this and respond to it.

The ability to select information is related to the general level of attention, that is, to the physiological activation and readiness to give an answer (**arousal** level). A

condition that can influence this process is the level of vigilance, which is the capacity to maintain a good level of attention for a prolonged period of time. Both arousal and vigilance are part of the attentional system.

How can we explain our visual system being able to choose which information is important and which is not, without first processing all the information available to determine what is most important? This is the paradox of intelligent selection. If attention operates very early, before much processing has been done, it is unclear how our attentional system can determine what is important and what is not; if instead attention operates relatively late, after a good deal of processing has already been done, it is easy to determine what is important and what is not, but much of the advantage of selection would be lost.

Selective attention to relevant information is possible by using heuristics based on both innate principles and ones learned through individual experience (Palmer, 2000).

1.2 Attentional Capture

It is evolutionarily advantageous to attend to some kinds of information rather than others. For example, moving objects are generally important for survival. For this reason, certain kinds of visual properties, called 'bottom-up' (such as uniqueness, colour, motion, sudden onset) can easily become targets of attention shifts.

Attention can shift automatically, drawn by 'bottom-up' stimulus features (**implicit attention capture**). These attention shifts have been referred to as reflexive, involuntary, or automatic. Stimuli that have been found to capture attention implicitly might not capture awareness as well. For example, there have been reports of stimuli

affecting reaction times without participants becoming aware of them (McCormick, 1997; Yantis, 1993; Posner, 1980). We refer instead to **explicit attentional capture** when a salient stimulus draws attention leading to awareness of its presence. This is also called endogenous orienting of attention, implying an aspect of cognitive or internal control.

Some other features become important with experience and must be learned. This is why, for example, one's own name in a text grabs attention before any other words. Processes that are under a perceiver's control and determine whether and what he or she will notice are called 'top-down'. We are talking about expectations, goals and attentional sets. For example, when participants know a target will be an item with a unique colour or a sudden onset, they adopt a specific attentional set, in the sense that they prepare themselves to receive a specific type of information.

There are several differences between these two mechanisms of orienting attention. Shepard and Muller (1989) found attention could be focused within 50 ms from the appearance of an exogenous cue but that at least 200 ms were required to engage attention endogenously. Enns and Brodeur (1989) found that children as young as six had attention captured automatically by an exogenous cue but were unable, or, at least, had difficulties, to use endogenous orienting mechanisms.

For exogenous cues, Posner (1980), Posner and Cohen (1984) and Maylor and Hockey (1985) found an 'inhibition of return' effect — the usual facilitatory effects at the cued location were replaced with inhibition if the cue-target delay exceeded 200 ms. This phenomenon, however, was absent occur for endogenous cues.

Usually, implicit attentional capture has been measured with four attentional paradigms — additional singleton, oculomotor capture, irrelevant feature search, and pre-cueing.

In the additional singleton paradigm, participants perform a visual search task, and an item in the visual display has a unique, distinctive feature that is unrelated to the search task; this item is never the target. For example, participants have to search for a uniquely blue item embedded within a display of yellow distracters. Normally, the time required to find the target increases as the numbers of distracters increases. However if, in the display, there is a further item (the singleton) uniquely coloured (for example, red) performance is slowed down relative to a condition without the singleton. This is because the irrelevant item captures attention even if participants have no reason to search for it.
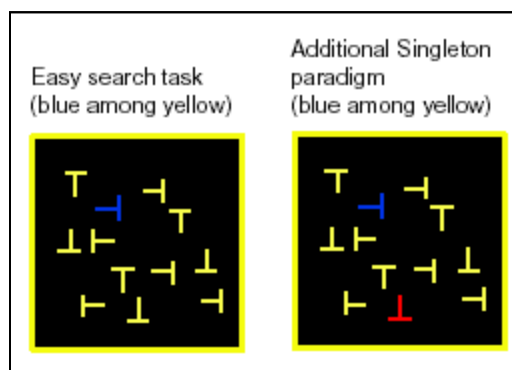
Figure 3 In an Additional Singleton paradigm, implicit attention is demonstrated by slower searching performance occurring when a display contains an additional stimulus uniquely coloured.

In the oculomotor capture paradigm, participants perform a visual search task in which eye movements are monitored. In this paradigm, the implicit attentional capture is demonstrated by eye movement toward an additional, irrelevant item. This irrelevant feature search paradigm is very similar to an additional singleton paradigm but with the important difference that the irrelevant feature can be the target of the search task. On each trial one of the items has a feature making it different from all the other items, but all the items in the display, including the target, are equally likely to have the distinctive

feature. When the distinctive item is also the target of the search, performance is speeded- up relative to the condition in which the singleton and the target are different items.

The pre-cueing paradigm refers to benefits participants involved in a visual search task have if the position of the target is preceded by a cue that indicates its likely position. Posner (1980) demonstrated that when the cue accurately anticipated the position of the target, participants were quicker to respond; but when it was not accurate, responses were slower. These patterns of results demonstrate that reaction times could be used as a measure of attention, in place of explicit reports.

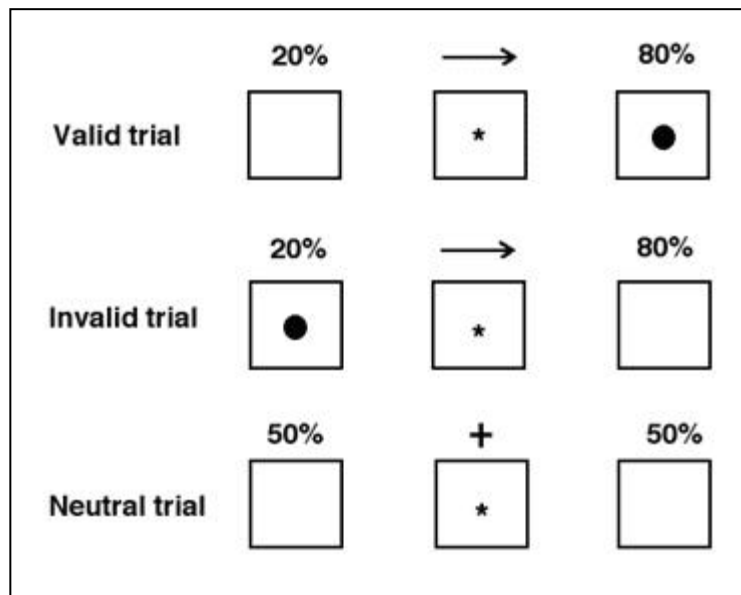**Figure 4** In Posner's paradigm (1980), implicit attention is measured as the advantage in reaction times for stimuli appearing in attended positions (valid trial) relative to reaction times to stimuli appearing in unattended positions (invalid trial).

Even if some features (such as abrupt onset, movement, colour) can capture attention automatically, this seems to happen only if the specific feature is important for

the task. In general, attention can be captured by any singleton when observers are in a singleton search mode, but if they are searching for a particular feature value, only cues with the same value will capture attention (Palmer, 2000).

While implicit attentional capture has been measured with experiments in which participants must ignore something they know to be irrelevant, but, for its features, automatically draws attention, explicit attentional capture paradigms measure the ability of participants to notice something unexpected but potentially relevant.

Because of our attentional limited capacity, sometimes this process can fail, giving rise to phenomena like inattentional blindness or change blindness.

Inattentional blindness and change blindness demonstrate we can be completely unaware of an object or event if we do not pay attention to it. This could happen even if the object or event is standing directly under our gaze. A failure to see an unattended object is known as inattentional blindness, while a failure to see unattended changes is known as change blindness.

CHAPTER 2

When attention fails: change blindness and inattentional blindness

2.1 Change blindness

Across saccades, blinks, blank screens, movie cuts, and other interruptions, observers fail to detect substantial changes to the visual details of objects and scenes (Simons, 2000). This inability to spot changes is known as change blindness.

Change blindness represents a failure to see large changes in a display when these changes occur simultaneously with a transient, such as an eye movement or a flash of the display. Researchers have long noted the existence of this particular kind of 'blindness' (Bridgeman, Hendry, & Stark, 1975; French, 1953; Friedman, 1979; Hochberg, 1986; Kuleshov, 1987; McConkie & Zola, 1979; Pashler, 1988; Phillips, 1974), but only recently an interest in this issue has been renewed.

For example, Grimes (1996) showed participants photographs for a later memory test. While they were scanning the image, and their eye movements were recorded, details in the photo were changed. Grimes demonstrated that observers often missed even large changes if the changes were introduced during an eye movement. The changes that were missed could be surprisingly large, involving a significant area of the picture; for example, many people failed to notice when two people exchanged heads!

Blackmore et al. (1995) obtained similar results showing a picture that shifted, probably inducing a saccade, at the same time as it changed.

Another common paradigm used to induce change blindness is the 'flicker' paradigm (Rensink et al., 1997). A 'flicker' paradigm is based on a rapid presentation of an original and a modified image, interrupted by a blank screen. Some changes are undetected even after one minute of sequential presentation. However, changes occurring in the central parts of the image are easier to detect relative to peripheral or 'marginal interest' changes.
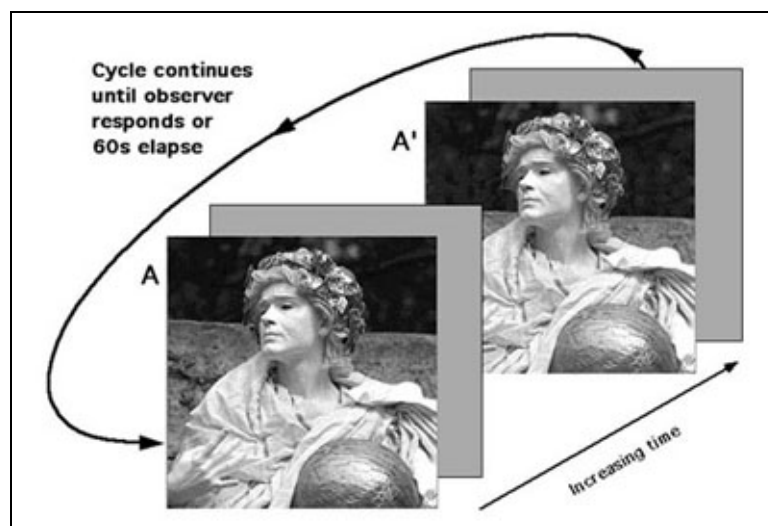
Figure 5 An example showing the 'flicker' paradigm (Rensink, 1997). The change in the image (in this picture, the displacement of the background wall) is difficult to notice, even when the images are observed for several seconds.

People also show change blindness when the original and altered images are separated by a 'mudsplash' (O'Regan, Rensink & Clark, 1999).

Figure 6 An example showing the 'mudsplash' paradigm (O'Regan, Rensink & Clark, 1999).

Change blindness can occur even in real-world situations.

For example, in a recent study (Simons & Levin, 1998), one experimenter approached a pedestrian, the subject, to ask for information. During their conversation, two other people interrupted them by carrying a door between the experimenter and the subject. During this passage, the subject's view was obstructed and the first experimenter was replaced by a different one. Only 50% of subjects noticed the change even though the two experimenters had different heights and builds, wore different clothing and had different haircuts (see Figure 7).

Figure 7 Change blindness can occur in the real world, as demonstrated by this experiment of Simons and Levin (1998). Half of its participants failed to notice the experimenter had been replaced by another person.

2.1.1 Suggested explanations

Simons (2000) reported five possible explanations for change blindness. Each explanation can account for some findings, but not for all of them.

1. Overwriting: The initial representation is simply overwritten or replaced by the blank interval or by the subsequent image. No visual record of the old image survives; when the new image comes, it simply replaces the old one. This explanation is regarded as the most plausible.

2. First impressions: Observers accurately encode the features of the initial object or scene, but then fail to encode details of the changed scene. If the goal of perception is to understand the meaning of a scene, then details of the scene will be irrelevant once we have reached this goal. If we encode features of the first scene, in order to extract its meaning, we may not check features of the changed scene provided that the meaning is constant. As a result, visual details of the second, changed scene are unrepresented.

3. Nothing is stored: Nothing about the visual world is internally stored. Only information extracted from the percept will be retained. This model predicts that few, if any, visual details of the image will be retained after the image disappears.

4. Everything is stored but nothing is compared: Since people can firmly hold two different beliefs without realizing they are contradictory, the same could happen with visual representations. This explanation suggests people may form a representation of each view separately, without ever being aware of differences between representations. A visual/cognitive system may assume the views are consistent unless something about the meaning of the scene (or the questioning of an experimenter) triggers a comparison.

5. Feature combination: Some features and objects are retained from the first view and others are retained from the second view. The resulting

representation is different from either of the views that contributed to it. Observers are unable to keep the two views separate, and partial representations of each are combined to form a new, coherent representation of the scene.

Even though none of these explanations can account for all the change blindness findings, they all seem to capture some aspects of the phenomenon.

2.2. Inattentional blindness

Inattentional blindness is a phenomenon in which people fail to notice stimuli appearing under their gaze when they are engaged with an attentionally demanding task. In the earliest studies on 'inattentional blindness' (Neisser & Becklen, 1975; Becklen & Cervone, 1983), people watched two superimposed, semi-transparent videoclips, each representing a simple dynamic scene (see Figure 8). Instructed to attend to one, they failed to notice an unexpected event happening in the other.
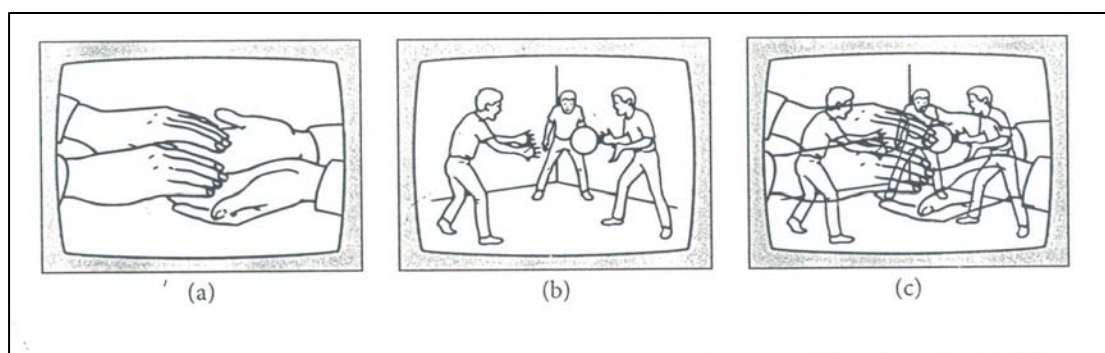
Figure 8 Participants engaged on monitor one of two superimposed, semitransparent videoclips, often miss one unexpected event happening in the other. (Neisser & Becklen, 1975; Becklen & Cervone, 1983)

Later, Mack and Rock (1998) introduced the 'static inattentional blindness paradigm' using computer-generated stimuli. In their experiments, subjects decided which of the arms of a briefly-flashed cross was longer. Engaged in this task, about half of the viewers failed to detect the appearance of a small black square in a different location of the screen (see Figure 9).

Figure 9 The inattentional blindness paradigm derived by Mack and Rock (1998).

An even more dramatic example of inattentional blindness came from a selective-looking experiment using a display where two teams play basketball (Simons & Chabris, 1999). When observers were counting the number of ball passes between the

members of one team, many viewers completely missed a person in a gorilla suit, intruding onto the sports ground (see Figure 10).

Figure 10 A striking example of inattentional blindness. Participants were instructed to count the number of ball passes between pl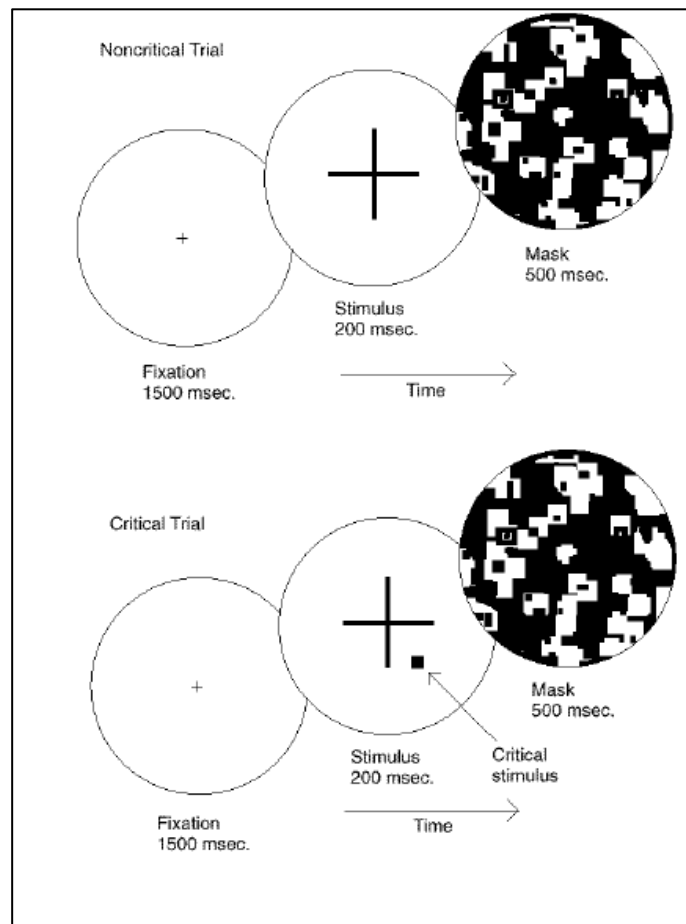ayers of a team. So engaged, most of them failed to notice a 'gorilla' traversing the sport ground, even when it stopped in the middle, to thump its chest (Simons & Chabris, 1999).

An important step for inattentional blindness exploration was taken by Most and colleagues (Most et al., 2001; 2005), whose protocol combined the rigorous control of the static inattentional blindness paradigm with the dynamic nature of the selective looking paradigm. They devised displays in which a few black and a few white items moved around at random, occasionally bouncing off the edges of the display window. Participants selectively attended to the total number of bounces made by either the black or white items. Under these conditions, many failed to detect a new item unexpectedly moving across the display, even when its shape and colour were unique.

Physical features of the unexpected stimulus (such as its colour, position in the display, movement) affect the probability of noticing it; however, an unexpected

stimulus can also go unnoticed when it is totally different in shape and colour from all the other shapes in the display. For example, nearly a third of participants missed an unexpected cross even if it was bright red in a completely achromatic scene (Most et al., 2001). Moreover, the more similar an unexpected stimulus is to the attended stimuli, and the greater is the difference from the ignored ones, less is the amount of inattentional blindness (Most et al., 2001).

The meaningfulness of the stimulus is also relevant — when a participant's own name or a happy-face icon takes the role of the unexpected stimulus, participants notice it more often (Mack & Rock, 1998), suggesting that top-down effects are involved in awareness.

The attentional load and the type of the main task influence the likelihood of seeing the unexpected, irrelevant stimulus (Lavie, 2005). Tasks implying a high perceptual load can eliminate distracter processing; whereas a high load on frontal cognitive processes increases distracter processing. This suggests that cognitive control is needed for actively maintaining a distinction between targets and distracters. Inattentional blindness was found even in the absence of objects that needed to be ignored, suggesting that allocating attention to target objects is sufficient to generate blindness to unexpected stimuli. However, the presence of nontarget stimuli creates a need to define the attentional set more sharply to better distinguish target stimuli from distracters, and this could lead to an increased failure to detect objects whose features are not included in the attended set (Koivisto & Revonsuo, 2008).

2.2. 1 Suggested explanations

It has been suggested that inattentional blindness might be due to the failure of unattended stimuli to engage perceptual processes, implying there is no conscious perception without attention, but alternative explanations have been proposed.

One of these argues that inattentional blindness is not a failure of perception or of attentional capture, but a failure of memory (Wolfe, 1999). Participants see the unexpected object, but by the time they answer the questionnaire, they have forgotten about it. So, any procedure that requires participants to report what they saw only after the fact may overestimate the amount of inattentional blindness. When stimuli to which subjects are inattentionally blind nonetheless prime responses to subsequently presented stimuli is consistent with this interpretation. For example, participants are more likely to complete word fragments with a word that has previously appeared on the screen, even when they failed to report seeing it (Mack & Rock, 1998).

An alternative explanation of inattentional blindness is that participants become aware of something additional happening in the visual display, but they fail to encode the properties necessary to encode this unexpected stimulus as something new, different, or noteworthy. In this view, inattentional blindness could be considered as a sort of inattentional agnosia (Simons, 2000).

Our data may help to take a stand in this controversial issue, still unsettled in the literature.

CHAPTER 3

The attentional cost of inattentional blindness

In this work we compared the effects of seeing and not seeing an unexpected, irrelevant item moving across the display during a visual attention task where participants were free to move their eyes — and therefore, also to inspect directly any event that attracted their attention.

Experiment 1

Method

Sixty participants, 21 males and 39 females, mean age 36 years; with normal or corrected-to-normal vision were tested individually. They were randomly assigned to one or the other of two conditions – one visual, single task: and one visual and auditory, dual task. There were 30 participants per condition; one dual-task participant, a nonnoticer, was removed from the analyses because her total number of errors was more than two standard deviations above the mean of her condition. The pattern of results was unchanged if this subject was included.

The visual stimuli we used were similar to those used by Most et al. (2001), and were presented on a portable computer – a 14" display Toshiba Satellite 1800-412. On each trial, four black (luminance=1.0 cd/m^2) and four white (luminance=87.4 cd/m^2) L and T shapes moved independently on random paths, at variable velocities, against a 10.6 x 8.0 cm grey (luminance=15.8 cd/m^2) background. Some trials also contained a

light grey (luminance=42.3 cd/m^2) cross with the same horizontal and vertical extent as the L's and T's, i.e. 8 mm, and the same thickness, i.e. 2 mm. As they moved, the black and white shapes could partially occlude each other, and occasionally bounce off the edges of the display window.

We prepared five separate trials, which were presented in the same order to all participants. The number of bounces was eight on the first trial, five on the second, six on the third, seven on the fourth and fifth. Each trial lasted 12 seconds. Participants were instructed to watch the display and keep a silent tally, using their fingers, of the number of times the white letters bounced off the edges of the display window. In the dual-task condition, participants also listened to either short stories (comprehension) or lists of words (recall), uttered by a computerized female voice. After each trial, participants reported the number of bounces they had seen; in the dual-task condition, they were also tested on their comprehension or recall.

All observers viewed the display from a distance of about 60 cm and completed five consecutive trials. The first two trials contained only expected events. Approximately 2.45 seconds into the third trial, the 'critical trial', a grey cross unexpectedly entered the display from the right side, traversed the screen horizontally along a virtual midline and exited the left side (see Figure 11). The cross remained visible for 7.15 seconds. After this trial, observers answered a questionnaire adapted from Most et al. (2005). They were asked to report whether they had seen anything other than the black and white L's and T's, something that was missing in the first two trials. If the answer was yes, they were asked to describe the colour, motion direction, and shape of the object. The shape could be picked among four different shapes, graphically represented in the questionnaire: an E-shape, a cross, a heart, and a triangle.
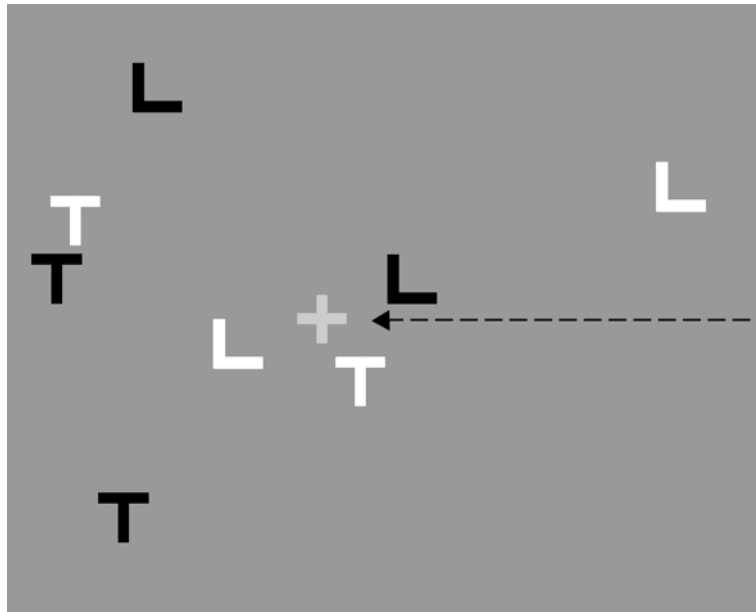
Figure 11. A single frame of one of the five dynamic displays used in Experiment 1. The arrow shows the path travelled by the cross, and was absent on actual display. The white and black shapes moved around on random paths, occasionally touching and bouncing off the edges of the display window.

Participants then completed a fourth trial (called a 'divided-attention trial', because the questionnaire had indirectly alerted them to the possibility that a novel object could appear), after which they answered a second questionnaire, identical to the first. On the fifth and last trial (the 'full-attention' trial), participants were simply asked to view the display, without performing any task. After this trial they answered a final questionnaire, identical to the previous two.

Results and Discussion

Overall, as reported on Figure 12, the cross was noticed by 42% of participants on the critical trial, by 68% on the divided-attention trial, and by 100% on the full-attention trial. The group of 25 observers that mentioned seeing a cross on the critical

trial (i.e. reported the shape correctly) includes participants who reported incorrectly the colour (10) and/or the direction of motion (3) of the cross; only nine individuals described all three attributes exactly. A further three participants indicated correctly either the colour or the direction of motion but not the shape.
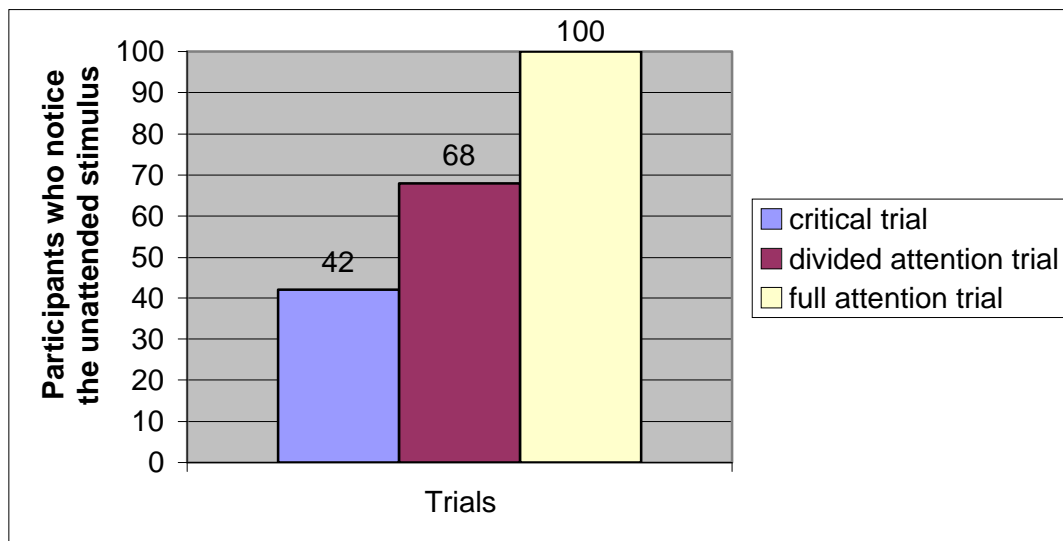
Figure 12. Participants who noticed the unexpected stimulus on the critical, the divided attention and the full attention trials.

First, we focused on the effects of inattentional blindness on bounce counting. On the critical trial, participants who had seen a cross made fewer counting errors than people who had not, $t(57)=2.95$, $p=.005$ (all t tests are two-tailed). This difference slightly increased, $t(57)=3.13$, $p=.003$, when the group of noticers was enlarged to include all participants who had answered affirmatively to the first questionnaire question; that is, those who reported to have seen the unexpected object, whichever the type and number of features correctly described—none for 2 people, at least one for 28 (see Table 1).

Experiment		Critical trial	Noncritical trial	Critical trial 2
1	Noticers (30)	.57 (.12)	.60 (.15)	
	Nonnoticers (29)	1.31 (.21)	.62 (.17)	
2	Noticers (15)	.47 (.17)	.33 (.16)	.67 (.19)
	Nonnoticers (22)	1.05 (.15)	.32 (.12)	.50 (.14)
3	Noticers (28)	.57 (.13)	.57 (.14)	.50 (.13)
	Nonnoticers (41)	.76 (.13)	.34 (.09)	.61 (.10)
4 (control)	Noticers (30)	.93 (.16)	.43 (.13)	.87 (.15)
	Nonnoticers (8)	1.13 (.40)	1.00 (.27)	1.00 (.27)
5 (control)	Noticers (26)	1.08 (.20)	.88 (.19)	.92 (.18)
	Nonnoticers (13)	.77 (.23)	.85 (.22)	1.23 (.26)
1-2-3 pooled	Noticers (73)	.55 (.07)	.53 (.09)	
	Nonnoticers (92)	.90 (.08)	.42 (.08)	

Table 1 Mean Number of Errors in the Bounce-Counting Task for Each Experiment.
Mean number of counting errors (standard error of the mean) for noticers and nonnoticers (number of participants), in critical and noncritical trials. Experiments 2 through 5 contained two critical trials. In the last two cells of the 'Critical trial' column, the values are the means of all the critical trials of Experiments 1, 2, and 3 (including those listed in the 'Critical trial 2' column).

Hereafter, we will code as 'noticers' participants answering 'yes' to the first question of the questionnaire, and as 'nonnoticers' participants answering 'no'. The difference in counting accuracy between noticers and nonnoticers was independently significant in both conditions, as shown in Figure 13.

How can this remarkable result be explained? The possibility noticers may be finer or more attentive observers in general (and thus, also more proficient in counting the bounces) must be discarded, since in the pre-critical trials noticers were as accurate as nonnoticers, both ts<1; nor was there an accuracy difference between noticers and nonnoticers in the divided-attention trial, t<1. A difference emerged only in the critical trial, and was caused by a marked drop in counting accuracy (relative to the pre-critical

trial) in nonnoticers, one-sample $t(28)= -3.58$, $p=.001$, but not in noticers, one-sample $t(29)< |1|$. The accuracy drop in nonnoticers consisted in a decrease of the reported number of bounces – they missed on average one bounce more than in the pre-critical trial.
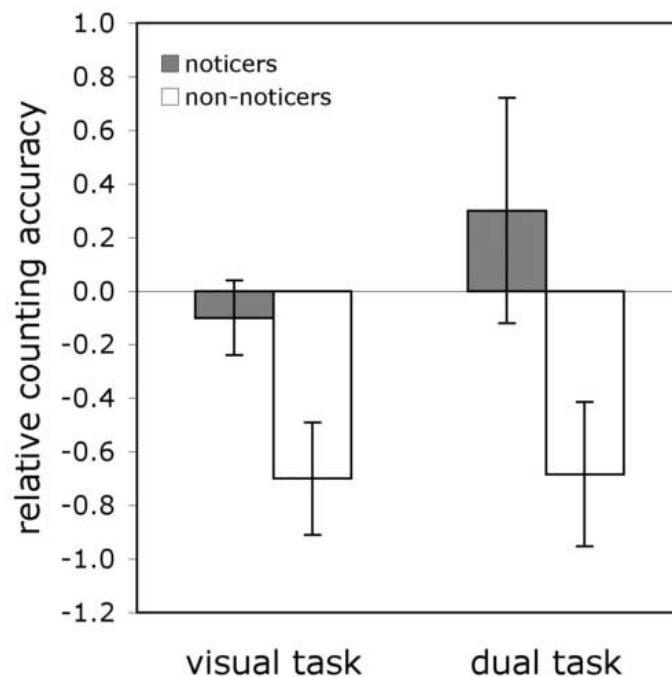
Figure 13. Relative counting accuracy on the critical trial, for noticers (i.e. participants reporting the unexpected object) and nonnoticers (i.e. participants who failing to report something). Accuracy is expressed as the absolute deviation from correct number of bounces on the second (pre-critical) trial minus the corresponding number on the third (critical) trial. On the critical trial, participants who saw the unexpected object were on the whole as accurate in counting bounces as they had been on the previous trial, whereas the accuracy of participants who saw nothing decreased significantly, regardless of whether they were only counting (visual task) or also listening to verbal material (dual task). Error bars indicate standard errors.

One criticism coming to mind is, after two trials, some participants may have become tired or bored and may thus have paid less attention to the display. This would have made them less likely to notice the new object *and* more likely to make counting errors. After the critical trial a questionnaire had to be filled out, which may have

awakened these participants' interest again. This potential scenario could be a trivial explanation of why, unlike noticers, nonnoticers had a drop in performance on Trial 3 (and not on Trials 1, 2, and 4). In Experiment 2, this confound was removed by alternating noncritical and critical trials and presenting the questionnaire only at the end.

Experiment 2

Method

Thirty-seven participants (18 males and 19 females, mean age 37 years) were tested individually. Three additional participants (one noticer and two nonnoticers) were discarded from the analyses because their total number of errors were more than two standard deviations above the mean; the pattern of results was unchanged if these subjects were included.

Apparatus, stimuli, and procedure were identical to those of the visual-task condition of Experiment 1, with one important exception. There were four consecutive trials, of which the first and the third contained no unexpected event, whereas the second and the fourth contained a grey cross. Hence, there were no divided-attention and full-attention trials, but a noncritical, practice trial (first), followed by a critical trial (second), followed by a noncritical trial (third), followed by another critical trial (fourth). Observers answered the questionnaire only after the fourth trial. The questionnaire was the same as in Experiment 1; additionally, participants indicated in which trial or trials the unexpected object had appeared. This time, we asked nonnoticers to *guess* the colour, motion direction, and shape of the novel object (picking the shape among the four alternatives) even though they claimed they had not seen the object at all.

Results and Discussion

Although in this experiment the cross appeared in two separate trials, the proportion of noticers (41%) was essentially the same as in the previous experiment. Interestingly, nonnoticers reported being absolutely sure they had not seen a new object, but when forced to guess picked the correct shape more often (.64) than chance (.25), one-sample $t(21)=3.68$, $p=.001$. A control experiment run on a separate sample of 22 subjects, asking them to pick one shape at random from the same set of four shapes, showed this choice was not due to a bias toward choosing a cross over alternatives – the cross was not selected (.18) more often than chance (.25), one-sample $t(21)<|1|$.

On the *first* of the two critical trials, participants who had seen a cross made fewer counting errors than people who had not, $t(35)=2.50$, $p=.017$ (see Table 1). The size of this effect was very similar to Experiment 1 (see Figure 2) – counting accuracy relative to the noncritical (third) trial was $-.73$ bounces for nonnoticers, one-sample $t(21)=-4.12$, $p<.0001$, and $-.13$ bounces for noticers, one-sample $t(14)<|1|$.

In the second critical trial there was no difference between noticers and nonnoticers, $t<1$; nor relative performance drop for either group. Note, the first and second critical trials are different in one important respect – the cross is a new object on its first passage, but not on the second. For this reason, we ran a new experiment, using two different unexpected objects in the two critical trials.

Experiment 3

Method

Sixty-nine participants (37 males and 32 females, mean age 29 years) were tested individually. Four additional participants (one noticer and one nonnoticers) were

discarded from the analyses because their total number of errors was more than two standard deviations above the mean; the pattern of results was unchanged if these subjects were included.

Apparatus, stimuli, and procedure were the same as in Experiment 2, except for two details. First, the two unexpected objects were a circle and a diamond rather than two crosses. They had the same colour (light grey), the same horizontal and vertical extent, and the same thickness as the cross. A circle and a diamond appeared in the second and fourth trials respectively for half of the participants, and in the opposite order for the other half.

Second, the number of bounces was counterbalanced across trials. For half of the participants the bounces were seven in the first trial, six in the second and third trials, and seven in the fourth; for the other half, the bounces were six in the first trial, seven in the second and third trials, and six in the fourth.

The questionnaire was the same as in Experiment 2, except that shapes could be chosen among eight different alternatives, depicted in random order – circle, diamond, square, triangle, cross, E-shape, H-shape, X-shape.

Results and Discussion

Only 28 (41%) of our observers reported seeing the novel object, and correctly recalled either the first of the two shapes (8), or the second (12), or both (8). Nonnoticers were sure they had not seen any unexpected object, but when forced to guess picked either the circle or the diamond more often (.44) than chance (.25), one-sample $t(40)=2.41$, $p=.021$. As in the previous experiments, noticers and nonnoticers performed differently in the critical and noncritical trials, as shown by the significant interaction between trial (critical, noncritical) and group (noticers, nonnoticers),

F(1.67)= 4.39, p=.040. For nonnoticers, counting accuracy relative to the third (noncritical) trial was lower both in the first critical trial, one-sample $t(40)= -2.80$, p=.008, and in the second critical trial, one-sample $t(40)= -2.43$, p=.020. For noticers, relative counting accuracy was not significantly different from zero in either the first or the second critical trial, both $ts(27)< |1|$.

It seems rather unlikely that most of our participants, in perfect unison, would withdraw their attention from the display on the second trial, become suddenly attentive on the third, and withdraw attention yet again on the fourth trial. Taken together, Experiments 2 and 3 show the interference of the unexpected object on performance is a robust one, and it is not due to accidental variations in attention over time. The unexpected, irrelevant object diverts attentional resources from the main task not when it is seen, but when it is unseen. Averaging across the three experiments, failing to notice the unexpected object led to more counting errors than noticing it, independent-samples $t(163)=3.09$, $p=.002$ (see Table 1). Relative to noncritical trials, counting accuracy in critical trials dropped for nonnoticers, $t(91)=5.65$, $p<.0001$, but not for noticers, $t(72)=0.20$, $p=.839$.

One potential, somewhat prosaic, explanation is attentional resources decrease purely because they are spread thinner in a trivial way. Noticers, by definition, discriminate a deviant item from the items they need to track, classify it as irrelevant to the task and hence manage to ignore it. Nonnoticers, being unable to identify the new object, may simply mistake it for an additional white letter, thereby adding to the five relevant items a further one. This is of course a harder, more error-prone task. Experiment 4 was designed to tackle this issue by actually presenting an extra white letter (a B or an S) in some of the trials. We reasoned that, if the pattern of errors for people who truly have to keep track of an extra white letter is the same as the pattern of

errors for nonnoticers in the previous experiments, the 'additional-item' explanation would be the most economical one.

Experiment 4

Method

Thirty-eight participants (10 males and 28 females, mean age 31 years) were tested individually. Four additional participants (all noticers; the pattern of results was unchanged if these subjects were included) were removed from the analyses either because their total number of errors was more than two standard deviations above the mean (2), or because they spontaneously reported counting bounces for the B and S (2).

Apparatus, stimuli, and procedure were the same as in Experiment 3, with the only exception being the unexpected object was a white letter (either a B or an S) rather than a grey shape (either a circle or a diamond). The extra letter had the same colour, horizontal and vertical extent, and thickness as the white L's and T's. The B and the S appeared in the second and fourth trials respectively for half of the participants, in the opposite order for the other half. Note, as before, participants were asked to count the number of times the white letters bounced off the edges of the display window, which automatically made the additional white letter a relevant item, even though it never bounced.

The questionnaire was the same as in Experiment 3, except among the final eight shapes the circle and the diamond were replaced by a B-shape and an S-shape.

Results and Discussion

Thirty participants out of 38 (79%) reported seeing the unexpected white letter, and correctly recalled either the first of the two unexpected letters (3), or the second (7), or both (20). On the questionnaire, the nonnoticers failed to pick either the B or the S

(.125) more often than chance (.25), one-sample $t(7)= -1$.

The counting accuracy for the eight nonnoticers was constant in the trials containing the additional white letter, $t(7)<1$; their performance was actually the same across all trials (presumably, these participants remained focused on the L's and T's). The counting accuracy for the 30 noticers worsened in the trials containing the additional white letter, $t(29)= -3.04$, $p=.005$ (see Table 1). The effect was entirely due to a significant increase in the mean reported number of bounces relative to the noncritical trial: on average noticers counted an extra 0.5 bounces, one-sample $t(29)=2.98$, $p=.006$. This figure is significantly higher than the corresponding one for nonnoticers in Experiments 1, 2, and 3; independent-samples $t(120)= 3.99$, $p<.0001$. Lower performance in our previous experiments consisted mainly of a larger number of bounce misses – indeed, if only participants missing (as opposed to added) bounces on at least one of the two critical trials are included, the performance drop is significant in Experiments 1, 2, and 3 (nonnoticers, all ts> 3.0, all ps$<.01$), but not in Experiment 4 (either noticers or nonnoticers, both ts$< |1|$). The pattern of errors in the two blocks of experiments is therefore clearly different.

These results suggest that it is unlikely the inaccuracy induced by an unseen object in the previous experiments was caused by mistaking that object for an additional relevant item. In Experiment 4, when the identity of the extra item went unnoticed the counting performance was unchanged (whereas in the previous experiments it worsened), which implies the new object had failed to attract either implicit or explicit attention — as also speculatively suggested by, unlike in previous experiments, shape guessing was totally random. To affect performance, the new object had to be processed deeply enough to be included among the relevant items, but as a consequence it was recognized (whereas it remained unidentified in the previous experiments). Moreover,

treating the new object as a relevant item increased the mean reported number of bounces, and did not decrease it as in the previous experiments.

A result that appears partly at odds with our main finding comes from the work of Most et al. (2005). These authors report for their experiments, the critical-trial counting accuracy diminished for both noticers and nonnoticers, with a more pronounced effect for noticers. Unlike us, however, Most et al. used a fixation point. Because this could be important for understanding the discrepancy between our results and theirs, we ran a new experiment, identical in all respects to Experiment 3 except for the presence of a fixation point.
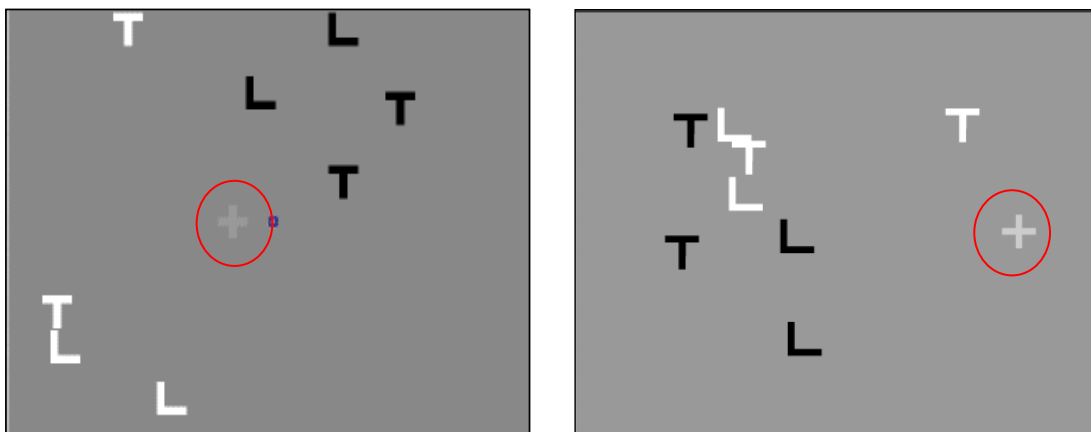
Figure 14. Two frames of Most et al.'s experiment (left) and our experiment (right). In our experiment there was no fixation point (the small blue square on the display's centre)

Experiment 5

Method

Thirty-nine participants (10 males and 29 females, mean age 24 years) were tested individually. One additional participant, a noticer, was discarded from the analyses because her total number of errors was more than two standard deviations above the mean. The pattern of results was unchanged if this subject was included.

Apparatus, stimuli, and procedure were the same as in Experiment 3, with the only exception being observers were instructed to fixate on a small blue square located in the centre of the screen, similar in all respects to the fixation point used by Most and colleagues (Most et al., 2001; Most et al., 2005).

Results and Discussion

Twenty-six participants out of 39 reported seeing the novel object, and correctly recalled either the first of the two shapes (7), or the second (8), or both (9), or neither (2). Although the only difference between Experiments 5 and 3 was the presence of a fixation point, the results were markedly dissimilar.

First, the probability of noticing the unexpected object was significantly larger in Experiment 5 (fixation point: 67%) than in Experiment 3 (no fixation point: 41%), independent-samples $t(106)=2.67$, $p<.009$. This may not be surprising if one considers the unexpected object, during its translation across the centre of the screen, passed right behind the fixation point (as in the experiments of Most and colleagues). Second, unlike in Experiment 3, nonnoticers picked *neither* the circle *nor* the diamond (.38) more often than chance (.25) in the final questionnaire, one-sample $t(12)<1$. This suggests any subliminal processing of the novel object was reduced relative to Experiment 3.

Third, and most importantly, for nonnoticers counting accuracy relative to the third (noncritical) trial was *not* significantly different from zero in either the first critical trial, one-sample $t(12)<1$, or the second critical trial, one-sample $t(12)=1.44$, $p=.175$ (see Table 1). For noticers, it was not significantly different from zero in either critical trial, both ts$(26)<1$.

A divergence between the results of Experiments 3 and 5 suggests the unseen, irrelevant object draws attentional resources away from the main task when participants

are free to track the moving targets, but not (or not nearly as much) when they are forced to fixate on a point. An economical explanation stems from the fact in the latter case the counting task is more difficult. Tracking a number of items in chaotic motion closely enough to detect whether they touch the borders of the screen is much harder if one is unable to look at them directly. Indeed, averaging across the three trials of interest, the number of counting errors was significantly larger in Experiment 5 (.96) than in Experiment 3 (.56), $t(106)=3.79$, $p<.0001$. This was true for both noticers and nonnoticers (both ps<.03). More difficult tasks demand more attention; more attention devoted to primary tasks implies that less attention is available for secondary activities, such as subliminal monitoring of extraneous objects. Processing of task-irrelevant stimuli has indeed been shown to depend upon the level of cognitive load in the relevant task (e.g. Lavie, 2005).

General Discussion

In our no-fixation experiments, only about 40% of observers noticed the unexpected, irrelevant stimulus. A remarkable finding considering the display could be explored freely; that in two of three experiments the stimulus itself appeared not on one but on two separate trials, and each time it was clearly visible for seven seconds. Our data suggest, if it entered awareness, the novel object could be rapidly classified as unrelated to the visual task (typically, because of a mismatch in the 'shape' dimension) and disregarded, at no extra cost. If it was unconsciously perceived, however, the novel irrelevant object lowered performance in the task. This shows that attention capture can occur without awareness (McCormick, 1997; Most et al., 2005; see also Rensink, 2000, 2004), and this type of attention capture is costly.

A decline in performance in those who failed to see the new irrelevant stimulus

is hard to explain as a combination of failure-to-identify *and* mislabelling-as-relevant, because, in fully comparable circumstances (Experiment 4), relevant stimuli influenced performance if and only if they were identified as such. Furthermore, the way in which additional relevant items affected counting performance was significantly different from the way in which additional irrelevant items had. Consistent with this argument is, although letter shapes were always present among the questionnaire alternatives, nonnoticers tended not to pick those. Indeed, they picked the correct object (cross, circle, or diamond) more often than chance. Such a choice is suggestive of subliminal processing.

In Most et al. (2005), any accuracy decrease for nonnoticers was always quite slight, and became significant only when data from seven experiments were pooled. The results of our Experiment 5, where we also failed to find a significant decrement in performance for nonnoticers, suggests the presence of a fixation point in Most et al.'s experiments may have been the main factor responsible for this data pattern. Arguably, fixation makes the tracking task harder, thereby increasing the cognitive load and leaving less attention available for subliminal monitoring of novel objects (e.g. Lavie, 2005).

Most et al.'s (2001, 2005) counting task was more cognitively demanding than ours in two further respects. First, in our study, subjects used their fingers to count the bounces, whereas in Most et al.'s they kept the count entirely in their head. Second, in Most et al.'s critical trials, which lasted 15 seconds, the target letters bounced on average 18 times (range 10 to 26; S. Most, personal communication, July 2006). In our own critical trials, lasting 12 seconds, the target letters bounced on average 6.5 times (range 6 to 7). The high rate of bouncing may economically explain why, unlike us, Most et al. found a sizeable decrease in accuracy for noticers. At an average rate higher

than one bounce every second, even a relatively short inspection of the novel object was bound to divert the attention of an otherwise perfect noticer from the moving targets long enough that a couple of bounces would be missed. At our average rate of one bounce every two seconds, that would be less likely the case. It therefore stands to reason that, in Most et al.'s experiments, the noticers' advantage in being able to disregard the irrelevant object was offset by the large probability of missing bounces when attention was diverted from the main task to the object itself. Furthermore, whenever it was grey rather than having either the attended or the to-be-ignored colours, the unexpected object was quite inconspicuous against the grey background (Weber contrast ranged from −0.4 for dark-grey unexpected items to 0.5 for light-grey ones; whereas our cross had a Weber contrast of 1.7), hence adding to the time needed to recognize it and dismiss it (see Burkhardt, Gottesman, & Keenan, 1987).

In the real world, where we seldom are requested to keep fixating on a point while things happen around us, attentional shifts tend to be associated with eye movements. Thus, our experimental procedure (which reveals a significant accuracy drop in nonnoticers) may mirror daily-life conditions more closely than Most et al.'s (which does not). Explicit attention capture presumably triggers an eye movement to the object, and prompt-recognition of the object's irrelevance to the task will re-direct the eye back to the original target. Implicit attention capture, on the other hand, consumes cognitive resources without rewarding us with the information needed for shifting attention strategically. Outside the laboratory, hence, irrelevant stimuli may hamper some types of performance only when perceived subliminally.

Our results are relevant to the problem of the nature of inattentional blindness, still unsolved in the literature. Does the failure to report unexpected items reflect a sort of blindness (a failure to perceive them) — or rather a form of agnosia (a failure to

recognize them, see Simons, 2000) or amnesia (a failure to remember them, see Wolfe, 1999)?

Our finding of deterioration in counting accuracy in nonnoticers, but not in noticers, appears inconsistent with the idea that unattended items are either 'perceived-but-miscategorised' or 'perceived-but-forgotten'. Such accounts assume that nonnoticers *do* see the unexpected object, but then proceed either to misclassify it as expected or to forget it; they presuppose that *all* observers are actually noticers. Yet if this were the case, the cost should be equally large, or larger, when the object is assigned to the more distracting 'unexpected' category (as noticers do) rather than to the less distracting 'no-news' one (as nonnoticers do), or when a trace of the object is kept in memory until the end (as noticers do), rather than disposed of (as nonnoticers do). That is, performance should, if anything, be worse for noticers than for nonnoticers. Our experiments, that show a drop in performance for nonnoticers only, suggest that inattentional blindness is indeed a form of blindness.

CHAPTER 4

Auditory attention can cause visual inattentional blindness

The phenomenon of inattentional blindness shows that our impression we are constantly representing the world as complete and fully detailed is illusory. One might claim an unanticipated event goes undetected simply because an observer's attention is glued to the objects they are requested to focus on — flashed cross, bouncing items, moving ball. Although a novel item can be missed even when it appears at fixation (e.g. Koivisto et al., 2004; Strayer et al., 2003), there are indications this happens exactly because observers try to concentrate attention on their assigned target rather than on where they are fixating (Mack & Rock, 1998). If this were the correct explanation, one would expect a significant reduction in inattentional blindness if observers were not asked to maintain attention on parts of the scene other than the one where the new object appears. For example, if the main task were non-visual, and the visual display could be explored without constraints. Alternatively, the unexpected event might be missed because the visual attention assigned to the task is unavailable for a new object presented in the same modality (Duncan et al., 1997; see also Rees et al., 2001). This also leads to the prediction that inattentional blindness would essentially disappear if observers were engaged in a non-visual, as opposed to a visual, attentional task.

A strictly related question is, will concurrent engagement in two tasks, one visual and one non-visual (as listening to the traffic bulletin while driving) augment inattentional blindness (as failing to notice an ice patch lying on the street, say, thirty

metres ahead)? And, would this depend on the type of auditory task (e.g. on whether we are trying to memorize the steps of an itinerary someone is dictating us over a cell phone, as opposed to simply comprehending what she is telling us)? The existence of cross-modal attentional links between sight and hearing has been shown across a wide range of dual-task situations (see Spence & Driver, 2004). For example, when people simulate driving and simultaneously carry out a verbal task, both performances are impaired (Horswill & McKenna, 1999). However, it is unknown whether detection of an *unexpected* event would also be affected. It has been argued that simply attending to verbal material, without active engagement in a conversation, does not interfere with driving (Strayer & Johnston, 2001). This conclusion was based on a study in which participants tracked a target that flashed red or green at irregular intervals, and were asked to respond to red by pressing a button. No impairment in reaction to red lights was found when participants simultaneously listened to radio broadcasts, or to a book on tape. However, (a) the critical events were not unexpected, only the time of their occurrence was; and (b) the critical events occurred where the participants' eyes and attention were both focused.

In the work reported here, we searched for an answer to the above questions by using two types of auditory attention tasks (listening to a few sentences in order to understand them, listening to a list of words in order to remember them) in place of, or in addition to, a visual attention task (counting bounces in a dynamic display).

Experiment 1

Method

Ninety participants (32 males and 58 females, mean age 37 years) with normal

or corrected-to-normal vision were tested individually. They were randomly assigned to one of three conditions: (a) visual, (b) auditory, and (c) visual and auditory (dual task). Within the auditory task conditions, half of the participants were assigned to the comprehension condition and the other half to the recall condition (described in the next section). There were 30 participants per condition.

The visual stimuli we used were the same as those used in Experiment 1 of our previous research. We prepared five separate trials, each one consisting of four black and four white L and T shapes moving independently on random paths, against a grey background. Shapes periodically bounced off the edges of the display window.

Auditory stimuli were prepared using the *Italian Assistant, Language Assistant Series* software. They consisted of five short stories[1] in Italian (about 26 words each) and five lists of Italian words[2] (14 words for each list), uttered by a computerized female voice. An example of a short story would be, "Joe has to go to the drugstore to buy some gauze and plasters. To get there he must turn right at the crossing's traffic-lights". The comprehension questions for this story would be: (1) "Where does this person have to go?", (2) "What does he have to buy?", (3) "In which direction does he have to turn to get there?". An example of a word list would be, "Flower, Bag, Mountain, Dog, Chair, Pen, Blackboard, Puppy, Book, Window, Candle, Light, Wall, Airplane".

In the auditory task conditions, each of the five trials was coupled with a different story (comprehension condition) or word list (recall condition). Participants were told they had to listen because their comprehension, or recall, would be tested at the end of the trial.

The visual stimuli were identical to those used in Experiment 1 of our previous research. We prepared five trials, which were presented in the same order to all

participants. In each trial four black and four white L and T shapes moved randomly, sometimes bouncing off the edges of the display window. The third, the fourth and the fifth trials contained a grey cross entering the display from its right side and exited on the opposite side, remaining visible for 7.15 seconds. The number of bounces was eight on the first trial, five on the second, six on the third, seven on the fourth and fifth. Each trial lasted 12 seconds.

The 90 participants were distributed across five conditions.

In the visual-task condition, 30 participants were instructed to watch the display and keep a silent tally, using their fingers, of the number of times that the white letters bounced off the edges of the display window; after each trial, they reported the number of bounces they had seen.

In the auditory-task (comprehension) condition, 15 participants watched the display and listened to short stories; after each trial, they answered three questions about the story. In the auditory-task (recall) condition, 15 participants watched the display and listened to word lists; after each trial, they recalled as many words as possible.

In the dual-task (comprehension) condition, 15 participants counted the number of bounces made by the white shapes and listened to short stories; after each trial, they reported the number of bounces they had seen and answered three questions about the story. In the dual-task (recall) condition, 15 participants counted the number of bounces made by the white shapes and listened to word lists; after each trial, they reported the number of bounces they had seen and recalled as many words as possible.

All observers viewed the display from a distance of about 60 cm and completed five consecutive trials. The first two trials contained no unexpected event. Into the third trial (the 'critical trial'), the grey cross unexpectedly appeared (see Figure 11).

After this trial, observers answered the questionnaire adapted from Most et al.

(2005). They were asked to report whether they had seen anything other than the black and white L's and T's, something that was missing in the first two trials. If the answer was yes, they were asked to describe the colour, motion direction, and shape of the object. Shapes could be picked from among four different ones, graphically represented in the questionnaire – E-shape, cross, heart, triangle.

Participants then completed a fourth trial (called 'divided-attention trial', because the questionnaire had indirectly alerted them to the possibility that a novel object could appear), after which they answered a second questionnaire, identical to the first. On the fifth and last trial (the 'full-attention' trial), participants were simply asked to view the display, without performing any task. After this trial they answered a final questionnaire, identical to the previous two. Participants were debriefed at the end. Nobody reported having been familiar with 'inattentional blindness' concepts or experiments.

Results and Discussion

Averaging across all conditions, the cross was noticed (i.e. the shape was correctly reported) by 38% of the participants on the critical trial, by 72% on the divided-attention trial, and by 100% on the full-attention trial. On the critical trial, only 15 individuals out of 90 correctly described all three attributes (shape, colour, and direction of motion) of the unexpected object. Detailed data per trial and experimental condition are shown in Table 2.

condition	critical trial					divided-attention trial			
	seen something new?	shape	color	motion	all three attributes	shape	color	motion	all three attributes
visual	20	17	12	15	8	23	14	19	11
dual	10	8	3	3	1	18	8	16	8
auditory (expt 1)	12	9	7	7	6	24	17	23	16
auditory (expt 2)	22	21	22	17	17	25	24	24	22

Table 2 Number of observers (i) reported seeing something new on the critical trial; that is, gave an affirmative answer to the first question of the questionnaire; (ii) reported correctly the shape, colour, and direction of motion of the new object, on the critical trial and on the divided-attention trial. Data are shown separately for the three conditions of Experiment 1 and for the condition of Experiment 2. Each condition included 30 participants.

Performance in the auditory task. Comprehension and recall performances, measured respectively as the number of questions correctly answered and the number of words correctly recalled, were analyzed with two separate repeated-measures ANOVAs, where the within-subjects factor was Cross Presence (pre-critical vs. critical trial) and the between-subjects factors were Condition (auditory-only vs. dual task) and Inattentional Blindness (noticers vs. nonnoticers). An additional ANOVA was performed on bounce counting accuracy, with a within-subjects factor of Cross Presence (pre-critical vs. critical trial) and between-subjects factors of Condition (visual-only vs. dual task) and Inattentional Blindness (noticers vs. nonnoticers).

Performance in the auditory task (both comprehension and recall) was reduced when the visual and auditory tasks were combined, $F(1,26)= 9.59$, $p=0.005$ and $F(1,26)= 17.95$, $p<0.0001$ respectively.

The number of words correctly recalled dropped from the pre-critical to the critical trial, $F(1,26)= 5.56$, $p=0.026$. (In the comprehension condition, where the

answers to the final questions could partly be inferred from the general context, there was no significant effect.) A marginally significant interaction emerged between Cross Presence and Condition, $F(1,26)=4.02$, $p=.055$, because recall worsened in an auditory-only condition (from 5.07 to 3.87 words) but not in the dual-task one (2.73 words in both cases). In all likelihood, the lack of a performance drop in the latter case reflects a floor effect, due to the high attentional demands of the dual task.

The decline in recall was essentially due to noticers, as shown by a marginally significant interaction between Inattentional Blindness and Cross Presence, $F(1,26)=3.13$, $p=0.09$. More specifically, noticers recalled fewer words in the critical relative to the pre-critical trial (the difference amounted to 1.75 words and was significant, $p=0.04$), whereas the performance of nonnoticers did not change (the difference amounted to 0.18 words and was nonsignificant, $p>.1$). This might be simply explained by the fact that, unlike nonnoticers, noticers either became temporarily distracted from the auditory task when noticing the cross (interference), or kept a trace of the cross in memory until the end of the trial, in addition to the traces of the words (higher memory load).

Inattentional blindness. From the standpoint of their effects on inattentional blindness (see Figure 15), the comprehension and recall conditions were not significantly different, either alone, $\chi^2<1$, or within the dual task, $\chi^2<1$; hence, they were combined. Unsurprisingly, observers were much less likely to notice the cross when they had to simultaneously attend to two tasks, one visual and one auditory, rather than to a visual task only, $\chi^2(1, N=60)=5.55$, $p=0.018$. (See Table 2.) Surprisingly, however, there was no significant difference in the amount of inattentional blindness between people engaged in the dual task and people engaged in the auditory task alone, $\chi^2<1$. This was true only as long as the stimulus was unanticipated: in the divided-attention trial, the gap between the two conditions disappeared, $\chi^2<1$, and there was a

tendency for the cross to be noticed less often when the task was dual as opposed to auditory, $\chi^2(1, N=60)=2.86, p=0.09$.

The dual task also hampered detailed perception of the cross: the number of perfect noticers (participants who correctly reported all three attributes of the cross) was significantly smaller in the dual-task condition than in either the auditory, $\chi^2(1, N=60)=4.04, p=.044$, or the visual one, $\chi^2(1, N=60)=6.40, p=.011$.
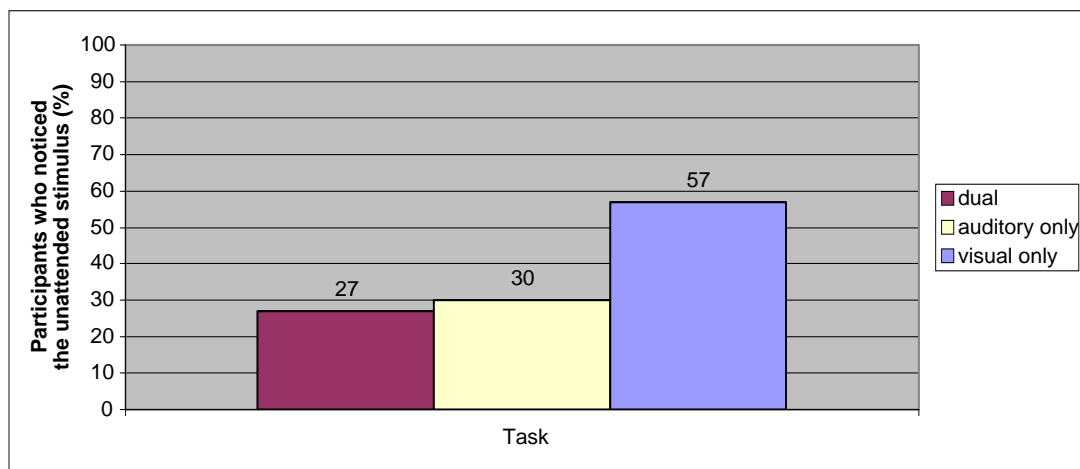

Figure 15. Percentage of participants who noticed the cross in the three different conditions.

On the whole, only one-third of our observers reported noticing something unexpected in the conditions in which they were listening to verbal material.

We found that inattentional blindness was as likely in the dual as in the auditory-only condition. Adding an auditory task to a visual task worsened inattentional blindness, but adding a visual task to an auditory one did not. A possible explanation is that of a ceiling effect. It has been shown that perception of irrelevant distracters is eliminated under conditions of high attentional load in an unrelated task (Rees et al., 2001). The load of the auditory task might be so high that it engages attention fully, exhausting available capacity and making the supplemental visual task redundant.

However, the higher attentional load of the dual task relative to the auditory-only task was clearly revealed by a corresponding decrease in both word retention and probability of full perception (or retention) of the cross. We must conclude that an auditory task, in itself, consumed attention only partly, and attentional capacity was not at ceiling.

Folk et al. (1992; 1993; 2002) argued that, to capture attention, a target must be part of a top-down attentional set. When a task is visual and the distracter is auditory, they are less likely to be part of the same attentional set, than when both are visual. Since in the auditory-only task the visual unexpected object is not part of the attentional set, it is also possible that, despite instructions to watch the screen, some participants may have 'defocused' the display (by converging their eyes either behind or in front of it) in order to 'focus' on the auditory task itself. Whereas participants were instructed to watch the screen and did keep their eyes on the monitor, by the third (critical) trial they would have realized that the visual stimulus was irrelevant to the task.

For this reason we ran a new experiment, where participants were explicitly told that it was crucial they watched a videoclip from start to finish, and they would be tested with a simple question about it at the end of each trial.

Experiment 2

Method

Thirty participants (1 male and 29 females, mean age 22 years) with normal or corrected-to-normal vision were tested individually. Five additional participants (three noticers and two nonnoticers) were replaced because, when questioned at the end, they admitted they had not watched all their videoclips from start to finish. All participants were tested with an auditory task – 15 participants were randomly assigned to the comprehension condition and 15 to the recall condition.

Apparatus, stimuli, and procedure were identical to those used in the auditory-only condition of Experiment 1, with the following difference. In Experiment 1 participants were asked to watch the screen, but no attempt was made to check to what extent they had actually done so. In Experiment 2 participants were explicitly instructed to watch (without counting or performing any specific visual task) each videoclip for its whole duration. They were told (a) this was important, and (b) they would be tested with a question about it at the end of each trial.

As in Experiment 1, after each trial participants answered three questions about the story (comprehension condition) or recalled as many words as possible (recall condition). In addition, after the first (practice) trial they were asked which colour the letters were, and after the second (noncritical) trial they were asked which colour the background was. After the third (critical), the fourth (divided-attention), and the fifth (full-attention) trials, participants answered the same questionnaire as in the previous experiment.

At the end of the experiment participants were asked if they had indeed watched the videoclip from start to finish, and were fully debriefed. Nobody reported having been familiar with 'inattentional blindness' concepts or experiments.

Results and Discussion

The number of participants that showed inattentional blindness in the trials of interest (critical and divided-attention; all subjects reported the cross in the full-attention trial) is given in Table 2. In the critical trial, this number was lower than in either the dual-task or auditory-only conditions of Experiment 1 (χ^2(1, *N*=60)=11.28, *p*=.001, and χ^2(1, *N*=60)=9.6, *p*=.002 respectively). Interestingly, although all 30 participants reported that they had watched each videoclip from start to finish, only 24 of them

correctly reported the colours of both sets of moving letters, i.e. black and white (a further 4 participants recalled one colour only), and only 21 correctly reported the colour of the background, i.e. grey. On the other hand, inattentional blindness was not linked to a scarce attentiveness to the visual display in general: the probability of missing the cross was basically the same (χ^2<1) among those who responded correctly to both control questions (17 participants, 5 nonnoticers) and those who did not (13 participants, 3 nonnoticers).

Like in Experiment 1, the decrease in number of correctly recalled words from the pre-critical (4.53) to the critical (2.00) trial was significant, F(1,13)= 16.61 , p=.001. Because participants were forced to watch the display for its whole duration, we expected a worse recall performance in Experiment 2 than in Experiment 1. Across trials, participants did indeed recall fewer words in Experiment 2 (3.33 on average) than in Experiment 1 (4.25 on average), F(1,28)= 12.42, p=.001.

This second Experiment confirmed the finding of the first one (the comparison between the two experiments is shown on Fig. 16), that the engagement of auditory attention, per se, can block an unexpected visual object from reaching awareness, even when no specific visual task is simultaneously carried out.
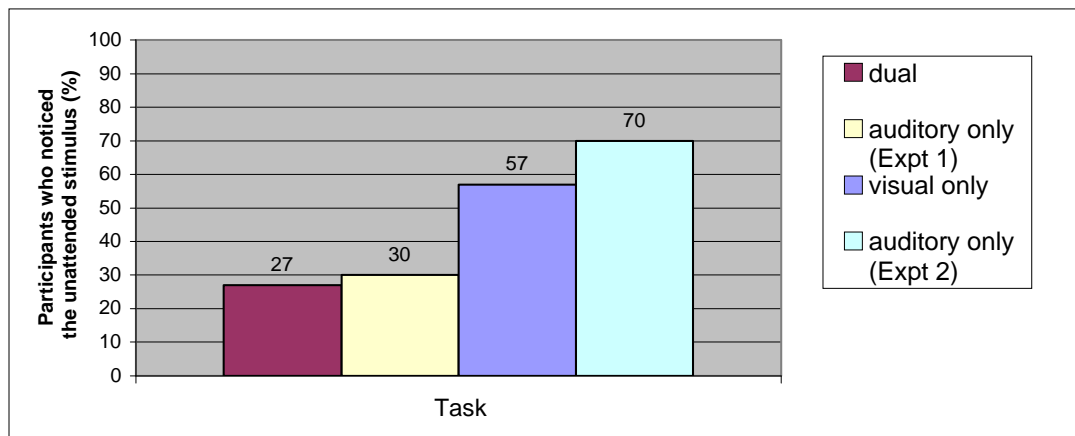
Figure 16. The graph shows the number of participants who noticed the cross in the four different conditions (three from Experiment 1 and one from Experiment 2).

The comparison suggests that, in order to focus on a verbal stream, people instinctively disengage visual attention — even when they are explicitly asked not to, and to the extent they can get away with it (hence, less in Experiment 2 than in Experiment 1). This automatic disengagement of visual attention pays back – the number of words correctly recalled was indeed significantly smaller in Experiment 2, which is when participants were forced to watch the visual event from start to finish. Nonetheless, a sizeable amount of inattentional blindness occurred even in this case, although participants not only were told that watching the display was a crucial part of the experimental task, but also reported, at the end of the experiment, to have fully followed the instructions.

General Discussion

Half of our observers failed to notice the unexpected visual object in the auditory-only condition, even though, in the absence of a tracking task, they were free

to move both their visual attention and their eyes over the display. This shows inattentional blindness does not need allocation of focused visual attention to concurrent stimuli (on an 'add here/subtract there' same-modality principle, as generally implied in the literature), but can be induced by allocation of auditory attention as well. Actually, the engagement of auditory attention was no less effective than the engagement of visual attention.

Our experiments indicate (a) in order to pay attention to a verbal stream observers automatically withdraw attention from the visual scene; and (b) they do this even when they are explicitly required to watch the scene, and affirm to have done so.

CHAPTER 5

Inattentional blindness in everyday life

5.1 The effects of cell phone conversations on driving

Situations in which we must pay attention to visual and verbal stimuli simultaneously are remarkably common outside laboratories. The importance of understanding how such tasks interfere with one another and with our ability to detect new visual objects is especially obvious when the consequences can be tragic, as in the case of driving accidents.

Use of a cellular phone is associated with a fourfold increase in the likelihood of a crash that will result in hospital attendance (McEvoy et al., 2005). The hazard is totally independent of the type of telephone—hand-held and hands-free devices entail equivalent risks. Whereas listening to a story or to a list of words trying to repeat each word in turn have no effect on driving performance, a normal phone conversation and much more complicated conversational tasks impair drivers' visual attention, suggesting that generating responses for a conversation and driving simply cannot run in parallel (Kunar et al., 2008).

More worryingly, a conversation with a passenger has about the same effects as a conversation on a cell phone; and even information-processing tasks much less engaging and emotionally loaded than a conversation, such as mental arithmetic or word games, entail significant costs (see Horrey & Wickens, 2006 for a meta-analysis). These costs are manifested primarily in terms of longer reaction times.

Cell phone conversations also impair explicit recognition memory for roadside billboards (Strayer, Drews & Johnston, 2003). Using a simulated driving task, authors found that participants engaged in cell phone conversations were more likely to miss traffic signals and reacted more slowly to those they did detect. Their reaction to a vehicle braking in front of them was impaired as well.

Authors proposed an inattentional blindness interpretation, in which the disruptive effects of the cell phone conversations on driving are due in large part to the diversion of attention from driving to the conversation. Even if participants had their eyes fixed on the target objects (the street, other vehicles, traffic signals) they failed to consciously perceive them because their attention was directed elsewhere.

Strayer and Johnston (2001) carried out experiments in which participants, engaged in a simulated-driving task, were instructed to react to briefly flashed red lights while ignoring green ones. Simultaneously listening to radio broadcasts, or to books on tape, did not interfere with reaction times. In these experiments, however, the appearance of stimuli was expected even if erratic. Our work crucially complements these studies by indicating that listening to a radio while driving, or to a portable audio player while walking or biking, can impair our reactions to unexpected stimuli.

5.2 The use of inattentional blindness by magicians

Magicians use techniques to divert attention and manipulate perception and awareness. For this reason, effects created by magicians are a relevant source of insight into the human mind. In particular, their 'misdirection' technique can provide interesting information to better understand the phenomenon of inattentional blindness.

We define as misdirection all those techniques that magicians use to draw participants' attention away from the 'method' (the secret behind the effect) and toward the effect (what the magician wants the spectator to perceive).

Physical misdirection refers to the control of attention via stimulus properties, and is similar to the concept of exogenous control of attention; the magician creates areas of high interest to capture an observer's attention, while the method is secretly carried out in an area of low interest. To this purpose, a range of techniques is used. For example, an important maxim in magic states spectators will look where the magician is looking. Repetitive movements, which lead the audience to a momentary relaxation, and non-verbal signs such as body posture, are used to manipulate the level of vigilance.

Psychological misdirection controls an audience's attention by manipulating their expectations; this is similar to the concept of endogenous control of attention. For example, to hide an action, magicians know if this action seems normal or justified, it will cause far less suspicion and will therefore probably go unnoticed. Another way of reducing suspicion is by keeping spectators in suspense as to what they are about to see; for this reason, a trick should never be repeated.

Macknik et al. (2008) suggest that misdirection can be applied in an overt or a covert manner. In the first case a magician diverts the attention of participants by redirecting their gaze. In the second case, the magician diverts the focus of attention without manipulating the participants' gaze. In this last case, spectators can be looking directly at the method of the trick without being aware of it.

Blindness to events generated by a magician with covert misdirection is very similar to the paradigms of change blindness and inattentional blindness.

Kuhn and Tatler (2005) monitored participants' eye movement during the performance of a magic trick (a magician made a cigarette 'disappear' by dropping it

below the table). The main purpose of the research was to determine whether participants missed the trick because they had not been looking at it or because they did not attend to it (irrespective of the position of their gaze). The authors observed detection rates were not influenced by blinks, by saccadic movements or by how far the cigarette was from the centre of vision at the time of the drop. Participants missed the trick even when they were looking at it, in the same way as participants miss the unexpected item in inattentional blindness experiments. The authors concluded that magicians manipulate mainly the attention of spectators rather than their gaze.

Conclusions

"It is a well-known phenomenon that we do not notice anything happening in our surroundings while being absorbed in the inspection of something; focusing our attention on a certain object may happen to such an extent that we cannot perceive other objects."

Reszo Balint, 1907

Without attention, we often fail to notice unexpected objects and events, and even with attention, we cannot encode and retain all the details of what we are seeing. Inattentional blindness is a phenomenon in which people fail to notice unexpected stimuli when they are engaged in an attentionally demanding task.

In this research we tried to understand what happens to the unattended stimulus when it is unseen; if is it completely ignored or it is elaborated, even if unconsciously; moreover, we explored for the first time the possibility of generating inattentional blindness engaging participants in an auditory task, rather than a visual one.

We found that participants who failed to notice an unexpected object presented during a visual task performed worse on the main task (Experiment 1). With additional experiments we ruled out the possibility that the decrease in performance was either to accidental variations in attention over time (Experiments 2 and 3) or by mistaking the object for an additional relevant item (Experiment 4). Adding a fixation point (Experiment 5), made the effect disappear; demonstrating this occurred only when participants were free to track the moving targets, not when they were forced to keep

their eyes fixed.

We suggest the decrease in performance is the cost of an unconscious elaboration of the unexpected object. When the object enters awareness (as it happens for noticers), it can be rapidly classified as unrelated to the main visual task and disregarded, at no extra cost. However, even when it is not consciously perceived, the object is elaborated to some degree, and this elaboration continues until the object disappears. The cost of this elaboration is reflected in a performance decrease in the main visual task.

Since this happens only when participants are free to explore a display indicates this unconscious processing occurs only when there are free attentional resources; these are unavailable when participants are forced to keep their eyes on a fixation point. We suggest the unexpected stimulus causes an alertness that would normally generate an attentional shift; in conditions in which the diversion of attention is inhibited by an absorbing task, a fraction of the available attentional resources remains allocated to unconscious processing of a new stimulus. Such a portion is large enough to disturb performance, but not so large that the object can be recognized as task-irrelevant and accordingly ignored.

From a biological point of view, *total* blindness to the unexpected might not seem very useful, whereas this state of alert is functional inasmuch as it allows us to maintain our attention on the task at hand, unless and until the unattended object is classified as salient enough to become the new focus of attention. We demonstrated this state of alert comes with a measurable attentional cost. Our findings have one counterintuitive implication – irrelevant stimuli might hamper some types of performance only when perceived subliminally.

In the second part of our research, we demonstrated how the engagement of *auditory* attention can induce *visual* inattentional blindness.

Our observers were much less likely to notice an unexpected stimulus when they had to simultaneously attend to two tasks, one visual and one auditory, rather than to a visual task only. However, there was no significant difference in the amount of inattentional blindness between people engaged in the dual task and people engaged in the auditory task alone (Experiment 1). This was because although they continued to watch the visual display, some participants automatically withdrew their visual attention to better concentrate on the auditory stream (Experiment 2).

Our finding that inattentional blindness can be induced by the mere allocation of auditory attention adds a relevant contribution to studies reporting an increased risk of accidents when drivers are talking on a cell phone. We suggest this happens exactly because, to better focus on the conversation, drivers withdraw attention from the visual scene, thus impairing their reaction to unexpected stimuli, such as a pedestrian unexpectedly crossing the street. In our experiments, participants were unaware of this diversion of attention and were convinced to have watched the scene all the time, suggesting an attention shift toward the auditory stream occurred automatically and unconsciously.

Appendix 1

Stories used in the comprehension condition

- "MAURO DEVE ANDARE IN FARMACIA A COMPRARE DELLE GARZE E DEI CEROTTI. PER ARRIVARCI DEVE GIRARE A DESTRA AL SEMAFORO".

- The comprehension questions for this story would be: (1) "DOVE DEVE ANDARE IL PROTAGONISTA? (2) "COSA DEVE COMPRARE?" (3) "DOVE DEVE GIRARE PER ARRIVARCI?"

- "IL CANE ESCE DALLA PORTA, CORRE GIÙ PER LE SCALE E CORRE NEL GIARDINO A FARE FESTA AL PADRONE, POI TORNA IN CASA E CORRE A NASCONDERSI NELLA SUA CUCCIA".

- The comprehension questions for this story would be: (1) "DA DOVE ESCE IL CANE?"; (2) "A CHI VA INCONTRO?"; (3) "DOVE SI NASCONDE?"

- "LA BAMBINA LEGGE ALLA MAMMA IL LIBRO DEGLI ANIMALI CHE LE HA DATO LA MAESTRA, POI PROVA A RIPETERE DA SOLA LA POESIA CHE HA IMPARATO IERI".

- The comprehension questions for this story would be: (1) "COSA LEGGE LA BAMBINA?"; (2) "A CHI LO LEGGE?"; (3) "QUANDO HA IMPARATO LA POESIA?"

- "IL PRESTIGIATORE CHIAMA DUE PERSONE DAL PUBBLICO. AD OGNUNA FA SCEGLIERE UNA CARTA E DICE LORO DI MEMORIZZARLA, POI RIMETTE LE CARTE NEL MAZZO".

- The comprehension questions for this story would be: (1) "QUANTE PERSONE CHIAMA DAL PUBBLICO IL PRESTIGIATORE?"; (2) "COSA DICE ALLE PERSONE CHE CHIAMA?"; (3) "QUANTE CARTE FA SCEGLIERE AD OGNUNA?"

- "IL CINEMA DEL PAESE E' CHIUSO I PRIMI GIORNI DELLA SETTIMANA. AL SABATO E ALLA DOMENICA I BAMBINI CON MENO DI 4 ANNI POSSONO ENTRARE SENZA PAGARE".

- The comprehension questions for this story would be: (1) "QUANDO E' CHIUSO IL CINEMA?"; (2) "COSA SUCCEDE ALLA DOMENICA?"; (3) "I BAMBINI DI CUI SI PARLA QUANTI ANNI HANNO?"

Appendix 2

Lists of words used in the recall condition

- FIORE SACCA MONTAGNA CANE SEDIA PENNA LAVAGNA CUCCIOLO LIBRO FINESTRA CANDELA LUCE MURO AEREO

- TESTO SCUOLA GATTO POLTRONA DISEGNO PALLA CONIGLIO GIARDINO FOGLIO BALCONE FIAMMA SERA TAMBURO CUSCINO

- LETTO OCA ORO STRADA MARE AUTOBUS BANCA TAPPETO MAGLIA BOTTIGLIA BORSA MANIGLIA TOPO REGISTRATORE

- SCALA BENDA TEATRO GOCCIA ANELLO DENARO CAPELLI RAMO CHIAVE FOTOGRAFIA FIOCCO PRATO UVA NUORA

- CERA RUOTA PENTOLA CERCHIO EDERA LAMIERA GELATO CERAMICA GOMMA DIPINTO FILTRO GIOCO NASO VISO

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