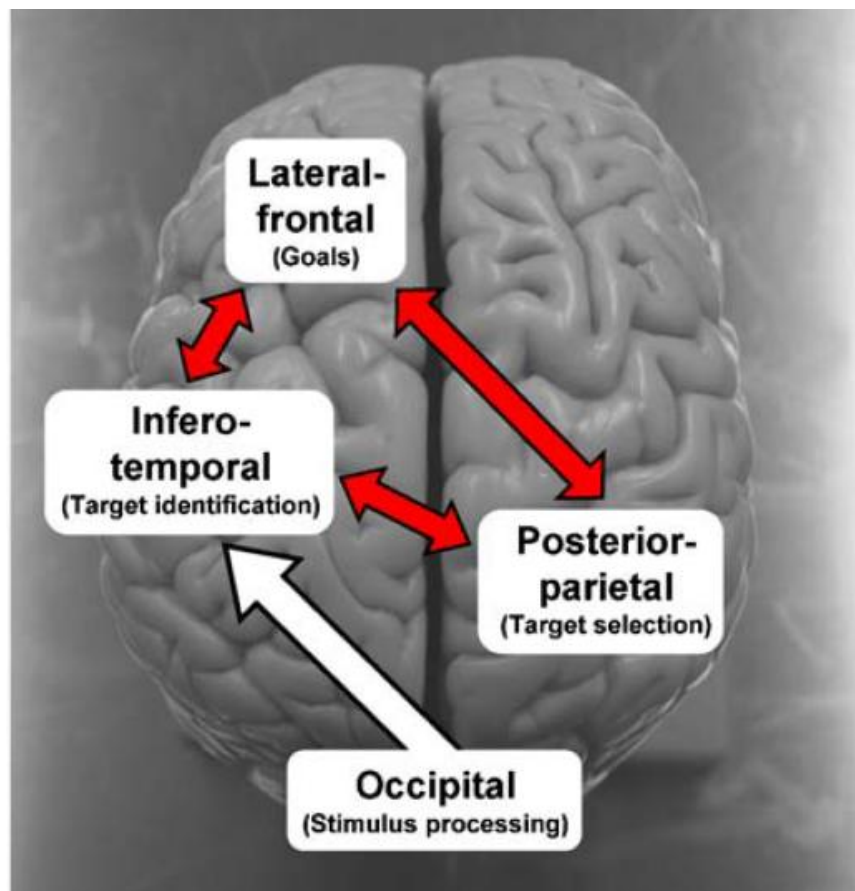# Attentional Blink

Processing deficit or adaptive biological mechanism?

Bachelor thesis Life Science & Technology
Manon van Asselt
Supervised by prof. dr. E.A. van der Zee
Department of Molecular Neurobiology
University of Groningen
June-July 2012

Abstract

Attentional blink (AB) is known in literature as a failure in reporting the second of two targets (T1 and T2) from a stream of stimuli (non-targets) when they are in close succession. The goal of this thesis was to find evidence in literature for the suggestion that AB is not just a processing deficit, but could be a useful adaptation of the brain, either directly or indirectly as a consequence of another mechanism. Surprisingly, no AB is found when T2 directly follows T1, also known as 'lag-1 sparing', indicating that non-targets play a crucial role in AB. Indeed, the selection of non-targets during T1 processing is suppressed to avoid competition between stimuli. According to 'contingent capture', some non-targets capture attention and are unintentional selected from streams of stimuli. If these non-targets are not suppressed, they will interfere with processing of T2 and cause consolidation of T2 to fail. I conclude that contingent capture is a plausible cause for AB. This hypothesis is supported by the findings that similarity between targets and non-targets and the mere presence of non-targets strongly influences the AB effect. Also, individuals who show no or little AB (non-blinkers) consolidate targets faster into working memory than individuals who do show AB, probably because of better suppression of non-targets. The conclusion of my thesis is that AB can be considered in two ways: a failure in suppressing non-targets or as the side-effect of contingent capture, which is in fact a useful adaptive mechanism. Unfortunately, these conclusions are only speculations, since evidence for contingent capture as underlying mechanism of AB is not abundant.
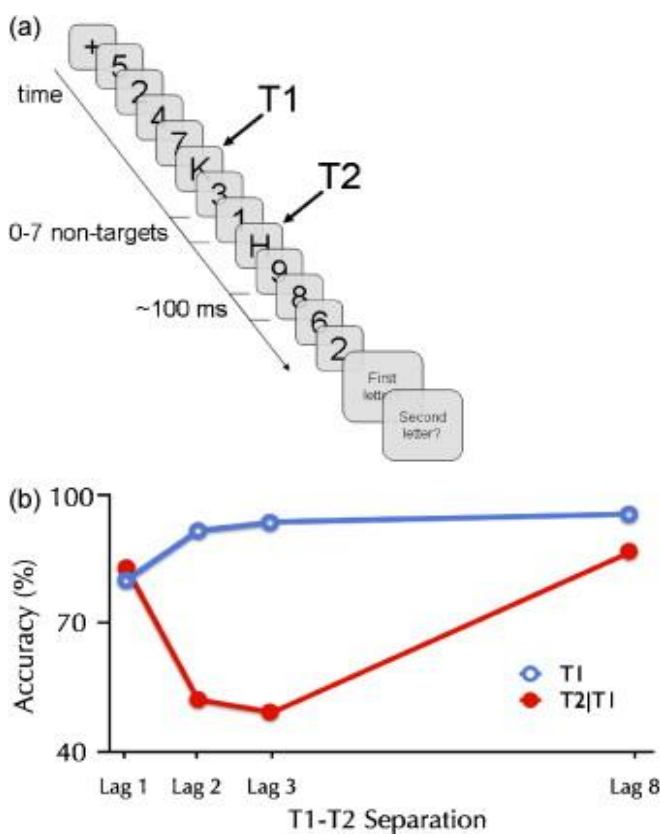
Contents

Introduction

Visual cognition is one of the most impressive capabilities of the human brain. Every millisecond streams of stimuli from the environment enter the brain via our eyes. However, we receive far more sensory information than we are able to process and store in our working memory. To deal with this overload of information, attention is used to select only important information for further processing and ignore irrelevant information (Dux & Marois 2009). The processing of information is executed by a collection of brain areas, referred to as the attentional network (Hommel et al. 2006). Because of the fact that attention plays such a crucial role in visual cognition, it is not surprising that over the last 50 years, understanding the underlying mechanisms of the attentional network has been an important goal of neuroscience (Dux & Marois 2009).

One of the topics research has focused on is the rate at which information is analyzed and encoded. This can be studied with rapid serial visual presentation (RSVP), shown in figure 1a (Chun & Potter 1995, Raymond et al. 1992). In this type of experiment, a rapid stream of stimuli is shown, for example, letters, digits, words or pictures. The task is to identify two targets (T1 and T2) among the other stimuli in the stream. Broadbent & Broadbent (1987) have demonstrated that identifying T1 comes with a cost and induces a relatively long-lasting deficit in the identification of targets presented after T1. In other words, T2 is often not reported. Raymond et al. (1992) investigated this phenomenon and concluded that attention seems to fail in selecting T2 presented during the interval of t = 180 ms to t = 450 ms. The authors suggested that attentional mechanisms 'blink' and were the first to introduce the term 'attentional blink' (AB) in literature (Dux & Marois 2009, Raymond et al. 1992).

Interestingly, Raymond et al. (1992) found some exceptional conditions under which AB does not occur, which can be seen in figure 1b. First of all, AB does not occur on every trial with a short target interval. T2 is in approximately half of the trials detected (non-blink trials) and in half of the trials missed (blink trials), although identical stimuli are used in the trials (Raymond et al. 1992). Also, no deficit in reporting T2 is seen when T2 is directly presented after T1 without the interference of non-targets. This phenomenon, known as 'lag-1 sparing', suggests that the non-target following T1 plays a crucial role in generating the AB effect (Dux & Marois 2009, Visser et al. 2011).

Figure 1. (a) The set-up of the attentional blink experiment as it is most commonly used. T1 and T2 are embedded in a stream of non-targets which is shown at a rate of 100 ms/stimuli. (b) The attentional blink (AB) effect. T1-T2 separation is presented in 'lags', with the lag being the relative position of T2 after T1 in the RSVP stream. Accuracy in reporting T2 drops from lag 2 to aproximately 50 %. Accuracy returns to baseline with an increase in the lag between T1 and T2. Adapted from Martens & Wyble (2010).

The generality of AB became questionable with the discovery of a small subgroup of people that appeared to be free from the capacity limitation (Feinstein et al. 2004, Martens et al. 2006). About 5% of the population shows little or no AB and are referred to as 'non-blinkers' (Martens & Johnsen 2009). It is conceivable to believe differences in mental capacity between blinkers (people who do show an AB) and non-blinkers are underlying the remarkable ability of non-blinkers to identify T2, such as a higher working memory capacity or general intelligence. Therefore, non-blinkers form an interesting group that could provide an answer about the fundamental nature of AB.

The earliest theories explain the AB phenomenon as a product of capacity limitations, either at an early target selection stage, or at a late consolidation stage (Martens & Wyble 2010). The goal of this thesis is to answer the question if AB is indeed a processing deficit, and if it is, at which stage the capacity limitation occurs. Or if there might be evidence indicating that AB is in fact a useful mechanism of the brain, either directly or indirectly as the outcome of another mechanism. So, is the AB really just an unfortunate failure of the attentional network or does it serve another purpose? One that maybe gives us an advantage in other situations?

The attentional network

What brain areas are involved in AB?

Neuroimaging studies have shown that the main areas that play a crucial role in AB are the infero-temporal cortex, the posterior-parietal cortex and the lateral-frontal cortex (Hommel et al. 2006). When stimuli enter the brain, registration in the occipital lobe is the first step. There, not only the target-related stimuli, but also non-related stimuli are processed (Hommel et al. 2006).

One could ask whether the AB phenomenon is caused by a sensory deficit in the occipital lobe and not an attentional deficit in higher cortical areas. Raymond et al. (1992) proved that the inability to identify T2 was due to an attentional, rather than a sensory, limitation. As is shown in figure 2, when subjects were asked to identify both targets, T2 performance was impaired if it appeared in the AB interval (open symbols). Strikingly, when subjects were asked to only report T2 and ignore T1, identification of T2 did not show a decrease (closed symbols). The same visual stimuli triggered different effects, depending on task requirements. This indicates that an attentional deficit and not a sensory deficit underlies AB.
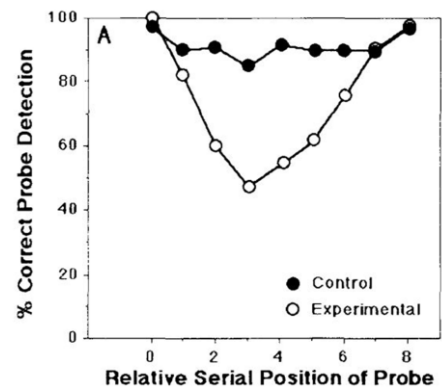
Figure 2. Sensory vs. attentional limitation. Percentages of trials in which T2 (the probe) was correctly detected, plotted as a function of the relative serial position of T2. Closed symbols represent the report of only T1. Open symbols represent the report of T1 and T2. Adapted from Raymond et al. (1992).

A selection has to be made to divide all stimuli into targets and non-targets. The infero-temporal cortex is involved in this selection process and responds to overall object features, such as shape (Desimone & Duncan 1995, Hommel et al. 2006). Evidence comes from the observation that the precise location of activation within the temporal cortex depends on the type of stimuli that is used (Todd & Marois 2004).

The right posterior-parietal cortex assists the infero-temporal cortex in the selection process, probably by dissolving the competition between stimuli representations in the infero-temporal cortex (Hommel et al. 2006, Liston et al. 2006). For example, Marois et al. (2000) found an increase in the right intraparietal sulcus – a lateral part of the parietal cortex – in conditions with high competition compared to low competition with a RSVP set-up.

Also lateral-frontal areas are associated with competition between temporally close stimuli in the RSVP stream (Liston et al. 2006, Marois et al. 2000). The lateral-frontal cortex may work together with the infero-temporal cortex in generating object templates (Desimone & Duncan 1995). These templates could be seen as expectations about targets, based on task requirements. Stimuli that match with object templates are potential targets and will be further processed (Di Lollo et al. 2005, Hommel et al. 2006). Another important role of the frontal cortex is that it is involved in the consolidation of stimuli into working memory (Desimone & Duncan 1995, Kranczioch et al. 2005).

Important to notice is that all of these areas seem to be correlated in some way with AB, but this does not automatically mean they work together and form a neural network. Besides co-activation in the same conditions, the areas should cooperate with each other to achieve a common goal. In the case of visual attention, that goal is selection, identification and consolidation of relevant stimuli into working memory (Hommel et al. 2006).

Gross et al. (2004) investigated the actual interaction between the temporal, parietal and frontal regions, measured by magnetoencephalography (MEG). Possible communication between eight different brain areas was measured, based on comparison between blink trials (in which only T1 was reported) and non-blink trials (in which both targets were reported). The connections could be divided into two categories, namely, stimulus-related and target-related connections. The first category connections reacted to each stimulus, regardless whether the stimulus was a target or non-target. The second category was modulated mainly by targets and showed little response to non-targets. In figure 3, Gross et al. (2004) visualized the connections between the measured brain areas. The connections that reacted to all stimuli primarily link the occipital cortex to left hemisphere areas (figure 3A). In contrast, the pattern of the target-related connections seems strikingly different from that of the stimulus-related network (figure 3B). The connections that reacted mainly to targets are the strongest between the right posterior-parietal cortex and cingulum, which is a bundle of white matter projecting to medial temporal areas, and also between left temporal and frontal regions (Gross et al. 2004). These findings contribute to the understanding of dynamics of the temporo-parietal-frontal network, or the 'attentional network' (figure 3C).
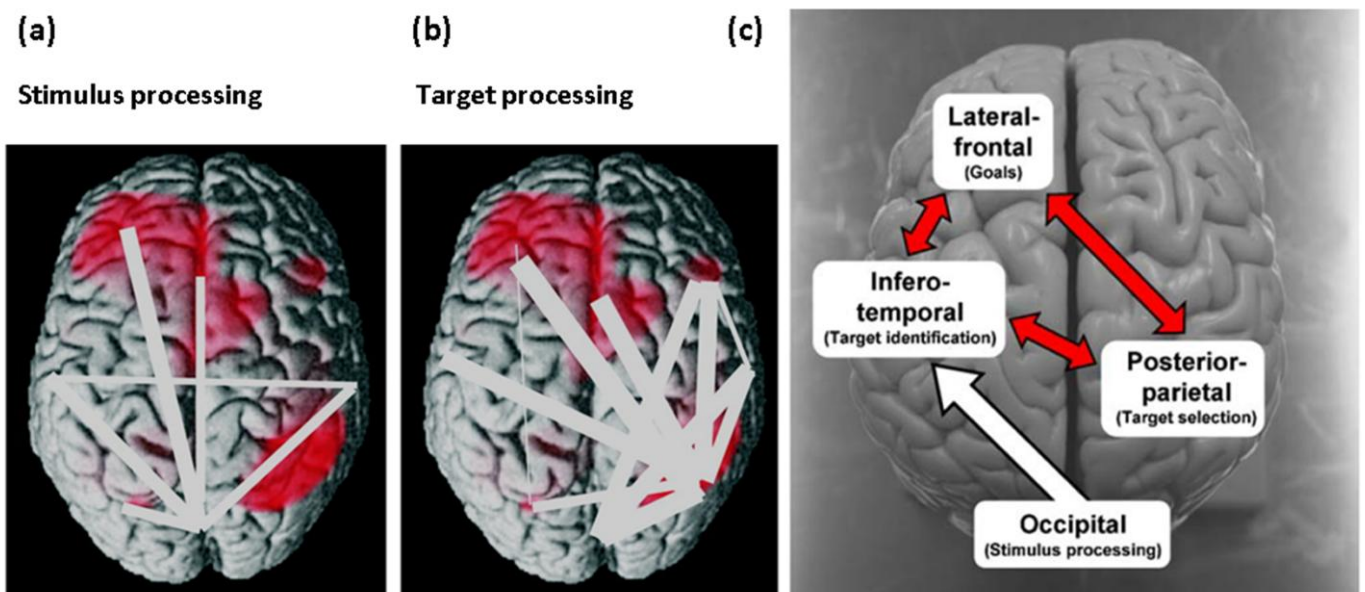
Figure 3. (a) The stimulus-related network and (b) the target-related network. The width of the wite line represents the strenght of the connection. (c) The components, functions and main interactions of the attentional network responsible for the attentional blink (Hommel et al. 2006). Figure 3a and 3b are adapted from Hommel et al. (2006). Figure 3c is adapted from Martens& Wyble (2010).

Is there a bottleneck?

The first theories stated that AB was due to some form of bottleneck in the stimulus processing (Chun & Potter 1995). What is meant by 'bottleneck' is that the attentional network is not able to cope with the processing of multiple targets, due to a capacity-deficit. If we follow the attentional network (figure 3c), the first possible step where the bottleneck could occur, would be target identification in the infero-temporal cortex. The idea is that when the infero-temporal cortex is occupied with the processing of T1, T2 is left vulnerable for competition with other non-targets. During the identification process of T1, T2 processing is delayed and not identified as a potential target, due to interference with non-targets (Raymond et al. 1992).

However, there is convincing evidence against the identification-related processing bottleneck from event-related potential (ERP) recordings. ERPs have been extensively used to study the temporal dynamics of AB (Kranczioch et al. 2003, Salti et al. 2012). For example, some studies have shown that not only non-blinked T2s, but also blinked T2s can induce a N400 component (Rolke et al. 2001, Vogel et al. 1998). The N400 component is a peaking ERP about 400 ms after target onset and is used as an electrophysiological marker for semantic processing of words (Rolke et al. 2001). This suggests that the early processing stages of targets remain relatively unaffected up to the semantic level and that AB is caused in a later stage of information processing (Ariga & Yokosawa 2007, Rolke et al. 2001). If the identification process in the temporal cortex does not form a bottleneck, could there be one in a later stage of processing? Another reasonable option is that the bottleneck appears after identification, namely, the consolidation stage. Collecting evidence for this hypothesis is complicated, because the concept of consolidation is poorly understood (Hommel et al. 2006). So, what do we know about the consolidation process?

An important feature of consolidation is that this process seems to produce a P300 potential in response to reported targets (Hommel et al. 2006, Kranczioch et al. 2007). In line with its name, the P300 component is a peaking ERP about 300 ms after target onset. T1 and T2 produce both a P300 in non-blink trials, irrespective of the length of the lag between T1 and T2 (Hommel et al. 2006). However, in blink trials the P300 has been found to be suppressed or even completely absent (Kranczioch et al. 2003, Martens et al. 2006, Vogel et al. 1998, Vogel & Luck 2002). Also, in non-blink trials the P300 component is delayed despite the absence of AB (Vogel & Luck 2002). This implies that the process underlying the P300 for T1 and T2 is postponed during AB. Since the dominant view of the P300 component is that it represents updating of working memory in response to targets, these results indicate that the bottleneck is the consolidation process that takes place in working memory (Kranczioch et al. 2003, Salti et al. 2012, Vogel et al. 1998).

Additional to the consolidation bottleneck model, AB could be explained as a shortage of attentional resources (Martens & Wyble 2010). A shortage of resources would be caused by the consolidation of the first target, therefore leaving not enough resources for the processing of the second target (Martens & Wyble 2010, Shapiro et al. 2005). Still, the question remains what mechanisms are responsible for allocation of attentional resources.

Avoiding the bottleneck

Lag-1 sparing

The inability to process multiple targets within approximately 500 ms is clearly shown in the attentional blink. Above 500 ms, a recovery in reporting T2 to the accuracy level of T1 is shown (see figure 1, Raymond et al. 1992). While the consolidation bottleneck model provides a good explanation for improved T2 performance when the temporal lag between targets increases, there are circumstances under which T2 is able to avoid the capacity limitations of AB and does not fit the bottleneck model. An example is lag-1 sparing, in which both targets can be identified with high accuracy when the two targets are not separated by non-targets (Kessler et al. 2005, Raymond et al. 1992, Visser et al. 2011). When T2 follows T1 directly (at lag 1), performance often reaches the baseline level obtained with only T1 reporting (see figure 1).

One of the most common hypotheses about lag-1 sparing is the integration hypothesis, which states that lag-1 sparing avoids capacity limitation by integrating the information of T2 with T1 (Nakatani et al. 2012). Lag-1 sparing could be explained by the bottleneck model if one describes the selection of information by attentional episodes. When the attentional network focuses on a target, other information can also be selected that falls into the same integration episode, while information that falls outside the episode is excluded (Hommel et al. 2006).

One possibility is that all episodes are of the same length. This would explain lag-1 sparing, because T1 and T2 could fall in the same episode. However, temporally identical episodes are difficult to combine with observations that individuals can process at least three targets in a row without any deficit, if no non-target is present between the targets (Di Lollo et al. 2005, Visser et al. 2011). This observation suggests that the attentional episodes are of a variable size. One of the possible factors that could influence the size of the episode is the presence of non-targets. The idea is that a target initiates an attentional episode. The episode stays open until a non-target appears which closes the episode (Hommel et al. 2006). This could happen because the non-target does not match the target template that is formed by the lateral-frontal cortex (Hommel et al. 2006).

Some studies have focused on the generality of lag-1 sparing. For example, Livesey and Harris (2011) observed surprisingly little lag-1 sparing when the targets were line drawings of familiar objects, despite the occurrence of a robust AB for these targets. This study is contradictory with the finding of lag-1 sparing by others that use alphanumeric characters as targets (Dell'Acqua et al. 2007, Nakatani et al. 2012). It seems that lag-1 sparing is strongly influenced by the type of stimuli used. An explanation for the difference between objects and letters could be that objects are more difficult to consolidate than letters and therefore need more attentional resources (Livesey & Harris 2011).

Non-targets capture attention

What is the role of non-targets?

Although the underlying cause for lag-1 sparing is still unclear, it raises questions about the role of non-targets in the AB paradigm. An explanation given for lag-1 sparing is that absence of a non-target between T1 and T2 allows faster processing of T1 or even integration of T1 and T2. Therefore, the delay of T2 processing is reduced and competition between T2 and non-targets avoided. So could it be that the presence of non-targets is the causal factor in the AB phenomenon?

To determine if indeed the mere presence of distractors reduce accuracy of T2 reporting, Visser et al. (2004) compared a non-RSVP condition with a RSVP condition. In the non-RSVP condition T1 was followed by a non-target and T2 appeared after a blank with the length of lag 1, 3 or 7. In the RSVP condition, T1 was preceded by non-targets and the lag also contained non-targets displayed at a speed of 100 ms. As is shown in figure 4, T2 performance was impaired by the presence of non-targets in the RSVP condition compared to the non-RSVP condition. This shows that non-targets strongly influence T2 accuracy, or the magnitude of AB.

Contingent capture

Attentional selection of information can be divided in at least two different ways. The first way is the ability of the subject to control what information should be selected based on goals or intentions, referred to as goal-directed selection (Ariga & Yokosawa 2007). The second way is stimulus-driven selection, in which the characteristics of a stimulus capture attention independently of the subject's goals or intentions (Ariga & Yokosawa 2007). This could impair performance, because sometimes unnecessary information is selected. If attention does not solely allocate to targets, the identification accuracy could be impaired (Visser et al. 2004). The phenomenon in which attention is captured by non-targets is known as 'contingent capture' (Ariga & Yokosawa 2007, Visser et al. 2004).

Contingent capture is an automatic selection mechanism and is suggested to be controlled by top-down processes, that check whether the selected information matches the object templates and disengage non-matching stimuli (Belopolsky et al. 2010, Niedeggen et al. 2012). Zhang et al. (2009) suggest that there are not only object templates for targets, but also for non-targets, which play a role in the actively suppression of non-targets. Support for this notion could be lend from Maki and Padmanabhan (1994), who showed that practice for 10 days improved T2 performance. However, when the non-targets were changed into a different category, T2 accuracy dropped to the level before practice (Maki & Padmanabhan 1994). The authors argued that an inhibitory template was used against non-targets.

The hypothesis that stimuli are compared to target templates and non-target templates is strengthened by the observation of a relationship between AB magnitude and the similarity between targets and non-targets (Chun & Potter 1995, Maki & Mebane 2006, Olivers 2006, Visser et al. 2004).
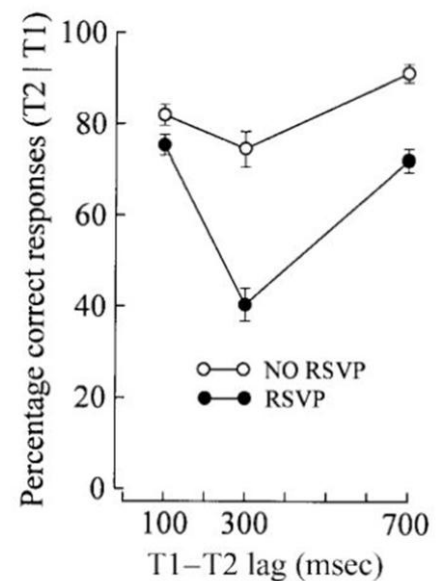

Figure 4. Mean percentage of correct identifications of the second target for the RSVP and the non-RSVP conditions, given that the first target was correctly identified. Error bars represent one standard error of the mean. Adapted from Visser et al. (2004).

In non-blink trials, a possible scenario is that non-targets between T1 and T2 capture attention, but top-down processes prevent them from being processed by disengage them. As a consequence, the non-targets cannot interfere with T2 and T2 is successfully reported. However, if top-down control normally prevents selection of non-targets, why it is able to do this in only half of the trials? Another possibility is that the non-targets are not captured by attention at all in non-blink trials. In both cases non-targets do not get through the selection process and form no competition for T2 so it successfully processed. So maybe contingent capture only occurs in blink trials. This would mean that when a non-target between the targets captures attention, top-down control is occupied with the processing of T1 and cannot inhibit the selection of the non-target. Therefore, the non-target forms competition and interferes with the processing of T2.

Blinkers versus non-blinkers

What are the differences between blinkers and non-blinkers?

The AB effect has long been considered to be a human information processing deficit with a high generality (Shapiro et al. 2005). Surprisingly, about 5% of the population shows little or no AB under conditions in which most people do show a blink (figure 5, Martens et al. 2006). This group, who are referred to as 'non-blinkers', was long time ignored, but in fact provide a unique opportunity to study individual differences in attentional selection.
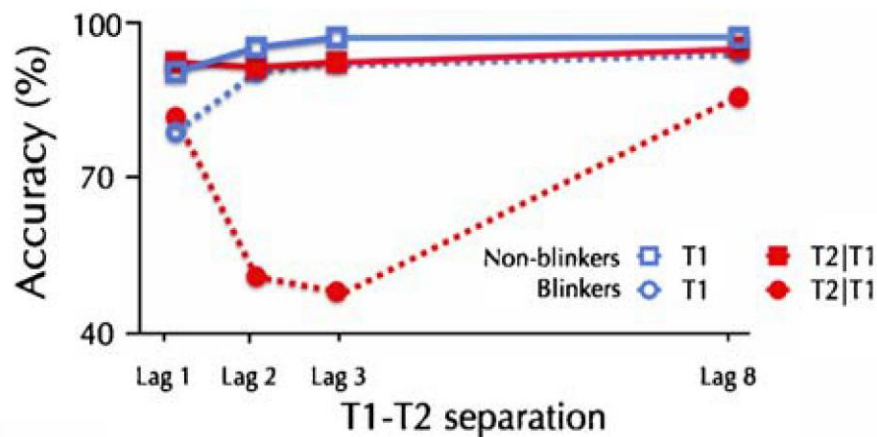
Figure 5. T1 and T2 accuracy of non-blinkers and blinkers. Blue lines represent the accuracy of reporting T1. Red lines represent the accuracy of reporting T2, given that T1 is correctly reported. Contradictory to blinkers, non-blinkers show no AB when asked to identify T1 and T2. Adapted from Martens et al. 2006).

A plausible hypothesis is that individuals with a relatively higher working memory capacity or higher general intelligence than other individuals may have better attentional control. A higher working memory capacity should be able to hold target properties more active despite the presence of non-targets and handle competition between targets and non-targets more efficient (Martens & Johnsen 2009). In this way, loss of T2 by interference could be prevented and therefore no AB occurs.

However, Martens and Johnsen (2009) found no evidence suggesting a relationship between AB magnitude and working memory capacity, short-term memory or general intelligence. They did find differences between blinkers and non-blinkers in a neuroimaging study. Analyses of P300 latencies showed that blinkers consolidate targets – especially T2 (in non-blink trials) – slower than non-blinkers. Their interpretation of these results is that non-blinkers are more efficient in ignoring irrelevant non-targets than blinkers are. Blinkers may direct more attention to each non-target than non-blinkers do (Martens et al. 2006). In other words, blinkers seem less able to ignore non-targets than non-blinkers and suffer more from contingent capture.

Interestingly, the ability to perceive two targets without AB is not as general as original was thought. Martens et al. (2010) used an AB task containing pictures rather than the more commonly used alphanumeric stimuli. Surprisingly, with this set-up, an AB magnitude similar to blinkers was induced in non-blinkers. This could be due to the higher difficulty level of pictures, which contains more features than alphanumeric stimuli. The authors hypothesize that non-blinkers have mastered an efficient strategy to separate targets and non-targets at an earlier stage of processing and therefore not blink in alphanumeric tasks. They probably select targets prior to full identification, allowing them to ignore non-targets and avoid an AB (Martens et al. 2010). It seems that non-blinkers cannot use the same strategy in the picture AB task, leading to an AB with a magnitude comparable to blinkers (Martens et al. 2010).

Discussion

The amount of visual stimuli far exceeds the capacity of the human information processing system. This means that we continually have to make decisions where to focus our attention on. Fortunately, visual attention selects only relevant information and prevents irrelevant information from being completely processed (Marti et al. 2011). However, in the attentional blink paradigm, this selection process seems to fail. When two targets are to be identified amongst a rapid stream of non-targets, almost all individuals show a deficit in reporting the second target (T2) when placed within approximately 500 ms after the first target (T1). This is called the attentional blink (AB) effect and is thought to be a capacity-limited processing deficit (Raymond et al. 1992). The goal of this paper was to find evidence in literature for the suggestion that AB is not just a processing deficit, but could be a useful adaption of the brain, either directly or indirectly as a side-effect of another process.

An explanation for AB as a processing deficit that has long dominated literature is the consolidation bottleneck model. This model states that T2 is not reported, because it cannot reach working memory (Hommel et al. 2006). Support comes from research indicating that missed T2s show no P300 component in ERP studies, which is correlated with the consolidation process (Kranzioch et al. 2003, Martens et al. 2006, Vogel et al. 1998, Vogel & Luck 2002). One of the assumptions from the consolidation bottleneck model is that attentional resources are limited and that T1 processing occupies most of attentional resources. As a result, when T2 is presented after T1, these resources are unavailable, leaving T2 vulnerable for interfering with other non-targets (Visser et al. 2011). However, when T2 directly follows T1, no AB occurs, also known as 'lag-1 sparing (Raymond et al. 1992). It seems that the selection of stimuli is mediated by attentional episodes, starting with the presence of a target and ending with the presence of a non-target (Hommel et al. 2006). This would explain why multiple targets can be reported without the interference of a non-target. Taking lag-1 sparing in account, the consolidation bottleneck model cannot explain all facets of AB. More likely is that non-targets form the causal factor underlying AB.

Based on my research in literature, I come to the conclusion that AB is formed by the following events: object templates are formed for targets and non-targets based on task demands, probably by the lateral-frontal cortex (Hommel et al. 2006, Zhang et al. 2009). Along the RSVP stream, stimuli are compared with these object templates. T1 captures attention and starts an attentional episode, because it matches the object template. Non-targets close the attentional episode and are actively suppressed by a top-down control, so further processing of these non-targets is inhibited (Niedeggen et al. 2012). T1 processing starts and occupies the top-down control processes. Therefore suppression of following non-targets seems to fail from approximately 200 till 500 ms after T1 is shown. Contingent capture occurs, in other words, when non-targets are captured by attention, they cause increased competition for attentional resources and impairment of T2 processing (Ariga & Yokosawa 2007). Therefore, T2 cannot be consolidated into working memory and AB occurs. Notable is the fact that capturing of attention by non-targets seems to be a random process, occurring in only half of the trials (Raymond et al. 1992). Further investigation should be done to discover what exactly triggers contingent capture in the RSVP stream.

So blinkers may be unable to process T2 because they use attentional resources exclusively for the processing of T1 and fail to inhibit selection of non-targets, captured by attention. The difference between blinkers and non-blinkers seems to be that non-blinkers are not simply better in detecting T2, but invest fewer resources into detecting T1 (Shapiro et al. 2005). Maybe the top-down control of non-blinkers stays in control of the selection process because it is not completely occupied

with T1 processing and remains able to suppress captured non-targets, just as in non-blink trails of blinkers.

The above mentioned scenario describes AB as a processing deficit caused by failure to suppress non-targets. However, contingent capture could also be seen as an adaptive mechanism. Top-down control may suppress the captured non-targets, but these processes do not control the entire selection process (Belopolsky et al. 2010). This would make the selection of useful information a very slow process and would require a lot of resources. Contingent capture of stimuli might be a necessary adaption in order to save attentional resources (Ariga & Yokosawa 2007). The way attention is allocated will mainly determine what we are aware of. Therefore, automatic selection could be helpful to attend to stimuli that may represent danger. It interrupts the voluntary task-related actions to focus attention to potential important stimuli. If one looks to contingent capture in this way, AB could be seen as a side-effect of an adaptive attentional mechanism.

Unfortunately, since the mechanisms underlying AB are not known, these are just suggestions. Despite the fact that from its discovery it has been shown that AB does not occur on every trial, neuroimaging studies comparing blink-trials and non-blink trials are not abundant in literature. Also, research about non-blinkers is in its infancy. I think non-blinkers form a unique opportunity for studies to compare the neural correlates of non-blinkers with blinkers. These individuals have an advantage in AB tasks. However, this ability could come to a cost in other situations, such as spotting potential important non-targets. Investigation aimed at the difference between blinkers and non-blinkers could provide information about the fundamental nature of AB.

In conclusion, I believe contingent capture provides a plausible explanation for AB. I conclude that AB is a side effect of the automatic selection of non-targets, which interferes with T2 processing. Therefore, T2 is not reported and AB occurs. However, further research should be done to confirm the causal relationship between non-targets and the AB effect.

Acknowledgements

References

Ariga, A., & Yokosawa, K. (2008). Contingent attentional capture occurs by activated target congruence. *Perception & Psychophysics, 70*(4), 680-687. doi:10.3758/PP.70.4.680

Arnell, K. M., & Larson, J. M. (2002). Cross-modality attentional blinks without preparatory task-set switching. *Psychonomic Bulletin & Review, 9*(3), 497-506. doi:10.3758/BF03196305

Becker, S. I., Folk, C. L., & Remington, R. W. (2010). The Role of Relational Information in Contingent Capture. *Journal of Experimental Psychology-Human Perception and Performance, 36*(6), 1460-1476. doi:10.1037/a0020370

Belopolsky, A. V., Schreij, D., & Theeuwes, J. (2010). What is top-down about contingent capture? *Attention, Perception & Psychophysics, 72*(2), 326-341. doi:10.3758/APP.72.2.326

Broadbent, D., & Broadbent, M. (1987). From Detection to Identification - Response to Multiple Targets in Rapid Serial Visual Presentation. *Perception & Psychophysics, 42*(2), 105-113. doi:10.3758/BF03210498

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology.Human Perception and Performance, 21*(1), 109-127.

Desimone, R., & Duncan, J. (1995). Neural Mechanisms of Selective Visual-Attention. *Annual Review of Neuroscience, 18*, 193-222. doi:10.1146/annurev.neuro.18.1.193

Di Lollo, V., Kawahara, J., Ghorashi, S., & Enns, J. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research-Psychologische Forschung, 69*(3), 191-200. doi:10.1007/s00426-004-0173-x

Feinstein, J. S., Stein, M. B., Castillo, G. N., & Paulus, M. P. (2004). From sensory processes to conscious perception. *Consciousness and Cognition, 13*(2), 323-335. doi:10.1016/j.concog.2003.10.004

Gross, J., Schmitz, F., Schnitzler, I., Kessler, K., Shapiro, K., Hommel, B., & Schnitzler, A. (2004). Modulation of long-range neural synchrony reflects temporal limitations of visual attention in humans. *Proceedings of the National Academy of Sciences of the United States of America, 101*(35), 13050-13055. doi:10.1073/pnas.0404944101

Kessler, K., Schmitz, F., Gross, J., Hommel, B., Shapiro, K., & Schnitzler, A. (2005). Cortical mechanisms of attention in time: neural correlates of the Lag-1-sparing phenomenon. *The European Journal of Neuroscience, 21*(9), 2563-2574. doi:10.1111/j.1460-9568.2005.04063.x

Kranczioch, C., Debener, S., & Engel, A. K. (2003). Event-related potential correlates of the attentional blink phenomenon. *Brain Research.Cognitive Brain Research, 17*(1), 177-187.

Kranczioch, C., Debener, S., Maye, A., & Engel, A. K. (2007). Temporal dynamics of access to consciousness in the attentional blink. *NeuroImage, 37*(3), 947-955. doi:10.1016/j.neuroimage.2007.05.044

Kranczioch, C., Debener, S., Schwarzbach, J., Goebel, R., & Engel, A. K. (2005). Neural correlates of conscious perception in the attentional blink. *NeuroImage, 24*(3), 704-714. doi:10.1016/j.neuroimage.2004.09.024

Liston, C., Matalon, S., Hare, T., Davidson, M., & Casey, B. (2006). Anterior cingulate and posterior parietal cortices are sensitive to dissociable forms of conflict in a task-switching paradigm. *Neuron, 50*(4), 643-653. doi:10.1016/j.neuron.2006.04.015

Livesey, E. J., & Harris, I. M. (2011). Target sparing effects in the attentional blink depend on type of stimulus. *Attention Perception & Psychophysics, 73*(7), 2104-2123. doi:10.3758/s13414-011-0177-8

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin & Review, 13*(1), 125-131.

Maki, W. S., & Padmanabhan, G. (1994). Transient Suppression of Processing during Rapid Serial Visual Presentation - Acquired Distinctiveness of Probes Modulates the Attentional Blink. *Psychonomic Bulletin & Review, 1*(4), 499-504. doi:10.3758/BF03210954

Marois, R., Chun, M. M., & Gore, J. C. (2000). Neural correlates of the attentional blink. *Neuron, 28*(1), 299-308.

Martens S, Dun M, Wyble B, Potter MC. (2010). A quick mind with letters can be a slow mind with natural scenes: individual differences inattentional selection. *PLoS One., 5*(10)

Martens, S., & Johnson, A. (2009). Working memory capacity, intelligence, and the magnitude of the attentional blink revisited. *Experimental Brain Research.Experimentelle Hirnforschung.Experimentation Cerebrale, 192*(1), 43-52. doi:10.1007/s00221-008-1551-1

Martens, S., Munneke, J., Smid, H., & Johnson, A. (2006). Quick minds don't blink: electrophysiological correlates of individual differences in attentional selection. *Journal of Cognitive Neuroscience, 18*(9), 1423-1438. doi:10.1162/jocn.2006.18.9.1423

Martens, S., & Wyble, B. (2010). The attentional blink: past, present, and future of a blind spot in perceptual awareness. *Neuroscience and Biobehavioral Reviews, 34*(6), 947-957. doi:10.1016/j.neubiorev.2009.12.005

Nakatani, C., Baijal, S., & van Leeeuwen, C. (2012). Curbing the attentional blink: Practice keeps the mind's eye open. *Neurocomputing, 84*, 13-22. doi:10.1016/j.neucom.2011.12.022

Niedeggen, M., Michael, L., & Hesselmann, G. (2012). Closing the Gates to Consciousness: Distractors Activate a Central Inhibition Process. *Journal of Cognitive Neuroscience, 24*(6), 1294-1304.

Olivers, C. N. L., & Watson, D. G. (2006). Input control processes in rapid serial visual presentations: Target selection and distractor inhibition. *Journal of Experimental Psychology-Human Perception and Performance, 32*(5), 1083-1092. doi:10.1037/0096-1523.32.5.1083

Raymond, J., Shapiro, K., & Arnell, K. (1992). Temporary Suppression of Visual Processing in an Rsvp Task - an Attentional Blink. *Journal of Experimental Psychology-Human Perception and Performance, 18*(3), 849-860. doi:10.1037//0096-1523.18.3.849

Rolke, B., Heil, M., Streb, J., & Hennighausen, E. (2001). Missed prime words within the attentional blink evoke an N400 semantic priming effect. *Psychophysiology, 38*(2), 165-174. doi:10.1017/S0048577201991504

Salti, M., Bar-Haim, Y., & Lamy, D. (2012). The P3 component of the ERP reflects conscious perception, not confidence. *Consciousness and Cognition, 21*(2), 961-968. doi:10.1016/j.concog.2012.01.012

Todd, J. J., & Marois, R. (2004). Capacity limit of visual short-term memory in human posterior parietal cortex. *Nature, 428*(6984), 751-754. doi:10.1038/nature02466

Visser, T. A., Bischof, W. F., & Di Lollo, V. (2004). Rapid serial visual distraction: task-irrelevant items can produce an attentional blink. *Perception & Psychophysics, 66*(8), 1418-1432.

Visser, T. A., & Ohan, J. L. (2011). Is all sparing created equal? Comparing lag-1 sparing and extended sparing in temporal object perception. *Journal of Experimental Psychology.Human Perception and Performance, 37*(5), 1527-1541. doi:10.1037/a0023508

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24*(6), 1656-1674. doi:10.1037/0096-1523.24.6.1656

Vogel, E., & Luck, S. (2002). Delayed working memory consolidation during the attentional blink. *Psychonomic Bulletin & Review, 9*(4), 739-743. doi:10.3758/BF03196329

Zhang, D., Zhou, X., & Martens, S. (2009). The impact of negative attentional set upon target processing in RSVP: An ERP study. *Neuropsychologia, 47*(12), 2604-2614. doi:10.1016/j.neuropsychologia.2009.05.008