The Time Course of Attention

It Is Better Than We Thought

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ABSTRACT—*What is the time course of attention? Research using rapid-stimulus streams has suggested that it is rather slow: Attention takes half a second to recover from processing one thing before it can process the next. This period is referred to as the* attentional blink, *and it is thought to reflect a fundamental bottleneck in conscious processing. If this period does exist, such a limitation would have severe consequences in real-life situations in which multiple events may rapidly succeed each other (e.g., in traffic). However, findings that support the attentional blink are at odds with other findings indicating that attention is not reduced, but enhanced, following potentially important occurrences. The article reviews evidence that these opposite effects are actually closely related. The attentional blink is a consequence of selection mechanisms that are not severely limited, but have an adaptive function: They enhance perception in response to relevant information but suppress perception in response to irrelevant information. It means that humans are better geared for real life than was previously thought.*

KEYWORDS—*attention; dynamics; time course; selection; suppression*

Imagine two relevant events happening in rapid succession. For example, the car in front of you switches on first its brake lights and then, a fraction of a second later, one of its turn indicators. How long does it take to switch your attention from one event to the other? The answer has clear implications for a world in which people are bombarded with information in ever-increasing quantities, at ever-increasing speeds.

To find out how long it takes to switch attention, researchers vary the time between two relevant events (targets), and then determine how long it takes observers to detect the second one after seeing the first. Figure 1A illustrates such a task. A rapid stream of characters appears at a single location, at a rate of about 100 milliseconds per item. Most of the characters (in this case, the letters) serve as distractors, but two of them (the digits) are targets, and the observer is asked to report both. Important for determining the time course of attention is the time between the two targets, referred to as *lag*. Because the items are presented at a fixed rate, lag also corresponds directly to the number of distractors between the targets.

Figure 1B shows the typical findings: Reporting of the first of the two targets is fine, but the second target is often missed when presented within about 500 milliseconds after the first. Analogous to the temporal blindness experienced during an eye blink, it is as if attention itself blinks for half a second while it is busy processing the first target. Hence the phenomenon is called the *attentional blink* (Raymond, Shapiro, & Arnell, 1992). Note that the attentional blink is not instantaneous: The second target is reported when it immediately follows the first target. Apparently, the blink needs about 100 milliseconds before it starts developing.

LIMITED CAPACITY

All prevalent theories stress limited cognitive resources as the cause of the attentional blink (Shapiro, Arnell, & Raymond, 1997). It is thought that the first target occupies a fundamental bottleneck related to the target's consolidation into consciousness. This bottleneck causes attention to be unavailable for the second target for up to 500 milliseconds. Figure 1C illustrates this type of account, and shows its intuitive appeal: The hypothesized availability of attention corresponds directly to the performance function in Figure 1B.

The topic of hundreds of publications in the past 15 years, the attentional blink has become a classic phenomenon in attention research, and the limited-capacity explanation is well established. The blink paradigm has been linked to central psychological concepts such as perception, short-term memory, response selection (e.g., which key needs to be pressed), arousal, and consciousness; it has also been used to draw conclusions about the cognitive limitations of various populations, such as those suffering from age-related cognitive decline, depression,

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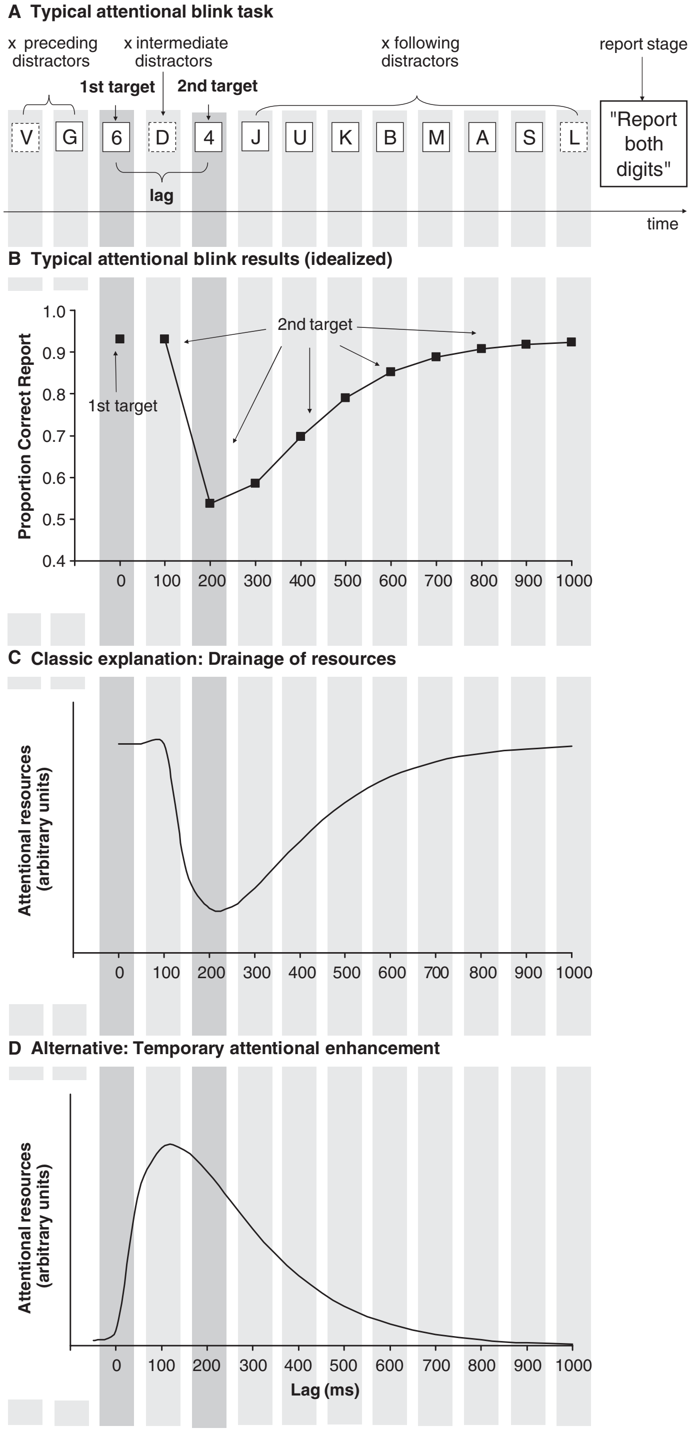

Fig. 1. A typical attentional blink task. In the task (A), participants are asked to report the digit targets from a stream of letter distractors all presented at the same location. Typical behavioral results (B) show a marked deficit for the second target for a period of about 500 milliseconds after the first; according to limited-capacity theories, this deficit (the attentional blink) is due to the temporary drainage of attentional resources (C). But a temporary enhancement of attention (D) suggested by a number of other tasks (e.g., Reeves & Sperling, 1986) may actually underlie the attentional blink, according to the reactive suppression account (Olivers, Van der Stigchel, & Hulleman, in press; Raymond, Shapiro, & Arnell, 1992).

stroke, impulsivity, blindness, cutting of the corpus callosum (the connection between the two brain hemispheres), dyslexia, Parkinson's, Alzheimer's, attention-deficit/hyperactivity disorder, and schizophrenia. For example, Rokke, Arnell, Koch, and Andrews (2002) found a deeper attentional blink in depressed people, and concluded that depression leads to a further reduction or slowing in the allocation of resources necessary for consciousness. Moreover, the conclusion that attention is so easily knocked out for half a second even in young healthy individuals has obvious implications for real-life situations involving the rapid succession of potentially important events, such as driving a car (Trick, Enns, Mills, & Vavrik, 2004). For instance, if a driver traveling at 100 km/h (approximately 60 mph) sees a hazard on the roadway ahead, half a second means the car will travel another 14 meters (15 yards) before the driver's foot even starts moving toward the brake. Because of these implications, it is of utmost importance to fully understand the underlying causes of the attentional blink.

TEMPORARY ATTENTIONAL ENHANCEMENT

Whereas the attentional blink suggests a temporary reduction in attention following an important event, other research suggests exactly the opposite, namely that performance temporarily improves after encountering relevant events (Nakayama & Mackeben, 1989; Reeves & Sperling, 1986). For example, Reeves and Sperling (1986) used a task similar to the attentional blink task but with two simultaneous streams, one consisting of letters, the other consisting of digits. The task was to monitor the letter stream for a specific target, which then served as a signal to switch to the digit stream and report as many digits as possible. By assessing which digits were and which were not reported from this second stream, Reeves and Sperling could determine which items received most attention. This resulted in a performance function quite opposite to that of the attentional blink: Probability of report first increased relatively rapidly with time, and then decreased gradually. Figure 1D shows the shape of this attentional enhancement function.

Outside the laboratory, such a temporary enhancement makes sense, because it prepares the organism for action in relation to the relevant event. It is probably best described as the little "jump" one experiences when, after an impatient period of anticipation, the phone finally rings, or the light finally changes to green. It is as if a brief burst of adrenaline rushes through one's system. In fact, this may be precisely what happens: A likely neurophysiological correlate of the attentional enhancement is the temporary increase in activation of the locus coeruleus, an area of the brain stem that responds to behaviorally relevant stimuli and is responsible for the cortical release of the attention-enhancing neurotransmitter noradrenaline (Aston-Jones, Rajkowski, & Cohen, 2000).

Thus, researchers are confronted with an interesting paradox: According to one account, target detection triggers an episode during which attentional resources are strongly reduced. Yet, according to the other, target detection triggers an episode during which additional attentional resources are being recruited. What's more, these two episodes show a remarkably similar time course. As Figure 1 shows, both reach maximum effect around 100 milliseconds after onset of their respective functions, and both last for several hundreds of milliseconds. The similarity is very suggestive: Are the two phenomena related? If they are, how then do they, at the same time, result in such opposite effects?

REACTIVE SUPPRESSION

A closer comparison of Figure 1C and 1D provides some clues. The attentional blink appears to be the vertical mirror image of the temporary attentional enhancement, but shifted by about 100 milliseconds. We could therefore reconcile these two opposite mechanisms, if we assume that the one acts in direct response to the other, within about a tenth of a second. This is what Raymond et al. (1992) originally proposed but later abandoned. However, we believe the idea deserves revival (Olivers, Van der Stigchel, & Hulleman, in press).

Note further from Figure 1D that when the first target triggers the temporary enhancement, this enhancement reaches its peak only when the target has already been replaced with a distractor. In other words, the wrong information is being enhanced. Because it is the duty of attention to keep irrelevant information out of consciousness, attention can respond to this powerful distractor signal only by strongly suppressing further input. If it is further assumed that this suppressive response takes some 100 milliseconds to take effect, then it may actually occur too late for the distractor itself. Instead, the immediately following item will be suppressed the most. If this item turns out to be a target, an attentional blink is observed.

According to this reactive suppression account, distractors, rather than targets, cause the attentional blink. If true, then there should be no blink as long as no distractors are encountered. This is exactly what my colleagues and I (Olivers et al., in press) observed. We asked participants to identify the targets in sequential triplets of items, such as . . . TDT. . . and . . . TTT. . . (T denoting a target, D denoting a distractor) embedded in a stream of distractors. Note that the final targets in these two triplets are in exactly the same temporal position relative to the first target, and therefore a limited-capacity account would predict an attentional blink in both cases. Yet performance differed remarkably: There was a clear blink for the final target in the TDT triplet, whereas there was no blink for any of the targets in the TTT triplet (see also Di Lollo, Kawahara, Ghorashi, & Enns, 2005).

Furthermore, if the suppression is indeed responsive to the incoming stimuli, it should be lifted when it is no longer required. In support of this, we (Olivers et al., in press) found that sequences like TDTT generated suppression for the second target (in response to the immediately preceding distractor), but not for the third (the suppression was lifted in response to the preceding target). Thus, unlike the limited-capacity account, which sees the attentional blink as a ballistic process that cannot be stopped once induced, the reactive-suppression account allows for relatively rapid adaptations to changing stimulation.

LESS IS MORE

A rather counterintuitive prediction is that performance should improve when the targets are made less relevant to the observer. This is because less relevant targets will trigger a weaker and shorter attentional response, and thus the distractors following the target will receive less attention. As a consequence, the reactive suppression will also be weaker.

This prediction appears to be borne out by our data (Olivers & Nieuwenhuis, 2005), as well as that of Arend, Johnston, and Shapiro (2006). These studies compared performance in standard attentional blink conditions to conditions in which participants were slightly diverted from the central task (in order to make it less relevant). For example, we asked participants to actively think about their holiday plans, or to perform the additional task of listening to a tune and detect a yell in it (Olivers & Nieuwenhuis, 2005), whereas Arend et al. distracted participants by presenting moving or twinkling dots in the background. All these manipulations had the same effect: The attentional blink was reduced. In other words, and contrary to what would be expected on the basis of limited-capacity accounts, taking away attentional resources from the stream may be beneficial rather than harmful.

Also telling is a study by Nieuwenstein and Potter (2006). They found an attentional blink when observers were asked to identify two specific targets from a stream. Interestingly, identification of the same targets improved considerably when observers were asked to report the entire stream, even though this task would presumably require more resources. Similarly, Ferlazzo, Lucido, Di Nocera, Fagioli, and Sdoia (in press) found a substantial attentional blink when observers were instructed to "report the individual letters" embedded in a stream, but virtually no attentional blink when observers were instructed to "report the syllable" made up of the very same letters in the same temporal positions.

All these studies suggest that having to process an object (and having the resources this requires) is not the main problem. What is detrimental is having to select a particular object. Selection leads to temporary enhancement, but also to the need for reactive suppression when the wrong object turns out to be enhanced.

It deserves mentioning that these benefits from diverting attention away from a specific target may well be limited to the attentional blink task, in which targets are quickly replaced by distractors (and thus diversion acts to take attention away from these distractors). In real-world circumstances (e.g., driving), relevant objects are usually not that quickly replaced, and taking attention away from them may be harmful.

CONCLUSIONS AND FUTURE DIRECTIONS

What becomes clear is that the attentional blink may not reflect the shortcomings of attention, but its strengths: Rather than a fundamental bottleneck that takes a whopping 500 milliseconds to clear, the attentional blink is a dynamic, adaptive gating system that adequately responds to changing stimuli, and does so fairly rapidly—within about 100 milliseconds. In the real world, 100 milliseconds is quick enough, because real-world objects usually tend to stay around for a little longer than that. It is in laboratory settings that allow for stimuli to change every 100 milliseconds or less that the true temporal limitations of attention are revealed. The important point here is that these limitations are far less dramatic than proponents of limited-capacity accounts claim. This is just as well: Humans probably would not have survived for long if our attention had been knocked out for half a second each time we saw something relevant.

This does not make the attentional blink task useless for the real world; it is still an important tool with which to investigate the dynamics of attention. Knowledge of these dynamics opens up, and puts limitations on, new ways of presenting information—for example, adaptive, rapid, serial presentations on the small screens of handheld devices (e.g., Oquist & Goldstein, 2003). What the present review suggests is that such presentations could easily be done at rates of up to 100 milliseconds per item (which is faster than normal reading speed) as long as the triggering of a strong attentional episode is prevented. In other words, users should not be required to select any specific word, because they will be likely to miss several other words.

Furthermore, if the attentional blink indeed reflects not the absence of attention but its active presence, then researchers may need to re-evaluate their conclusions about clinical populations in which the blink has been found to be deepened or prolonged (such as in the earlier-mentioned depressed observers; Rokke et al., 2002). Rather than reflecting a further narrowing and protracting of a cognitive bottleneck, the impairments may reflect decreased flexibility on a smaller underlying time scale, possibly leading to overzealous suppression in response to irrelevant information. Future research will have to focus on these underlying dynamics and especially on the neurophysiological mechanisms responsible for them (e.g., Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005). Ideally, clinical populations could then benefit from behavioral and psychopharmacological interventions that successfully modulate these small-scale dynamics.

Finally, the current research issues a general warning that we should not take an overarching time course of a psychological effect at face value, because the underlying microdynamics may be quite different from (and even opposite to) what the overall picture suggests. This is no doubt true for many areas other than the attention field—areas such as memory, motor control, and cognitive development. Probably one of the biggest problems in studying the cognitive system is exactly this: It never sits still!

Recommended Reading

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