Selective Attention

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A fundamental aspect of our cognitive activity is selection, by attentional mechanisms, of a portion of the vast amount of information we are confronting at any moment.

INTRODUCTION

0612.001 A fundamental empirical phenomenon in human cognition is its limitation. At any moment in time, a vast amount of information impinges upon our senses. Many studies show that we cannot fully process all this information, and that some of it appears to be lost. One trademark of a limited system is its need for selection. Given that not all the impinged information can be processed, it is mandatory to select which portion of it will be preferred. In theory, the selection can be random. However, people are able to perform a nonrandom selection. For example, drivers in a junction with traffic lights are able to focus on the lights rather than on other stimuli present in the scene. The mechanism in charge of the selection is termed 'selective attention'.

0612.002 Any type of selection presupposes the availability of some information in order to perform the very selection. Thus, some 'pre-attentive' processing must be performed prior to the operation of selective attention, and its output is used for the selection. The distinction between pre-attentive and attentive processing is essential in the study of selective attention.

0612.003 Extensive research over the last 50 years has explored the basic properties of selective attention. Many issues related to attention have been clarified, but questions concerning its operation are still debated among researchers. Perhaps the most basic question concerns the point in the processing stream of information where attention begins to operate. This issue, developed into a controversy known as 'early versus late selection', is reviewed first. We then review studies suggesting that there may be multiple levels in which selective attention operates.

EARLY VERSUS LATE SELECTION

It is useful to consider task performance as a stream 0612.004 of information processing starting with input (usually via our senses) and ending with output (usually, some behavioral action). A major question concerns the locus of processing at which selection is performed. As mentioned before, there is some initial pre-attentive processing at the input side, but up to what point? At what stage of processing does selection (and selective attention) begin? Because pre-attentive processing is by definition unlimited, whereas post-attentive processing is limited, one may answer this question by uncovering the point where limitation is first evident. This point is often called 'the bottleneck'. Two classes of studies, focal attention and divided attention, were used to explore this question.

Focal attention studies

In focal attention studies, subjects are required to 0612.005 focus on a subset of the stimuli presented to them and ignore all other stimuli in the scene. We focus on one such paradigm, the dichotic listening paradigm, but findings from other paradigms are similar. In a typical dichotic listening experiment, two auditory messages (e.g. two stories) are played simultaneously. Subjects are asked to monitor one message, usually by shadowing it (i.e. repeating verbatim), and ignore the other. Studies with this paradigm revealed an important difference between two types of task. In one type, the two messages differ by a physical property. For example, the messages may differ in their intensity or by their pitch (male versus female). In the second type, the messages differ by semantic content. For example, words denoting animate and inanimate objects are played simultaneously, and subjects are required to shadow the animate words.

Early studies showed a dramatic difference be- 0612.006 tween these two types of studies. When the messages differed in semantic content, subjects simply failed to perform the shadowing task. When the messages differed in a physical property, subjects could perform the shadowing task. This shadowing ability, however, was coupled with a profound inability to report the content of the ignored message. In one study the ignored message was repeated 35 times. In another study, the language of the ignored message was changed from English to German. Both changes were not noticed by the subjects. In contrast, subjects did notice a change of a physical property in the ignored message. For example, subjects immediately notice when the gender of the speaker of the ignored message changes. There is then a fundamental difference between processing of physical and semantic properties of stimuli. Moreover, processing of semantic information in a rejected/ignored message is dramatically limited.

0612.007 To capture these findings, Donald Broadbent proposed his influential early selection model of selective attention. According to this model, physical properties in the scene are processed in parallel and without any limitation. To process any semantic content, attention selects a physical property and acts like a filter: the semantic content carried by the selected physical property is recovered by higher level processes. Semantic information not carried by this physical property is lost. For example, attention may select a range of pitches corresponding to a female voice. Consequently, the semantic content carried by the female voice is processed, but other kinds of semantic information in the scene is lost. It is an 'early selection' model because selection is done early in the stream of information processing, at a point where only physical properties are available.

0612.008 Subsequent studies, however, indicated that pre-attentive processing is not as limited. Although subjects do not generally notice the content of ignored messages, they sometimes detect in them important information (e.g. their own name). Anne Treisman proposed her attenuation model to accommodate these findings. This model resembles that of Broadbent, with an important modification: the attention filter attenuates rather than blocks other stimuli. The implications of this modification are best understood with another important general assumption of standard cognitive models concerning the way we represent stimuli in our brain and how such representations reach consciousness. Namely, each representation has a variable level of activation. To reach consciousness, a representation has to accumulate a high level of activation. The resting level of activation of most representations is low and thus outside consciousness. Through perceptual processes, a stimulus impinging on our senses causes an increase at the level of activation of its representation that eventually leads to its conscious recognition. The resting level of different representations differs. Important representations or representations relevant to the current cognitive context have a higher resting level of activation and consequently need a smaller additional activation to be consciously recognized. We can now appreciate the difference between Treisman's and Broadbent's models. According to the attenuation model, non-selected stimuli can be processed as well, albeit to a lesser extent. However, if the resting level of activation of their representations is sufficiently high, the attenuated processing may still cause the representation to reach consciousness. This explains how subjects sometimes notice their name, a representation with a presumably high resting level of activation, in the ignored message.

The models of Broadbent and Treisman were 0612.009
based on studies using subjects' conscious report of ignored messages. Other methods, however, revealed that stimuli may be processed and affect behavior indirectly even when subjects cannot report them consciously. For example, some studies showed that words presented in the ignored message and not reported by the subjects may nonetheless affect the interpretation of the attended message. Late selection models were proposed to capture these findings. According to these models, semantic information is also processed pre-attentively. The bottleneck is between extensive pre-attentive (physical and semantic) processing and conscious report rather than between physical and semantic information.

The early versus late selection debate has not 0612.010
been settled with focal attention studies, partly because most such studies have an inherent problem: we cannot be certain that subjects indeed focus their attention on 'attended' messages. The ability of subjects to process portions of ignored messages may be explained as occasional shifts of attention to them. Studies based on direct report of subjects are problematic for another reason: ample evidence suggests that stimuli are often processed without being consciously reported. Late selection models can dismiss poor direct report of ignored messages as a reflection of interfering processes that mask the pre-attentive processing of these messages.

Divided attention studies:

Focal attention studies led to 'bottleneck' theories. 0612.011
Another class of explanations emerged from

divided attention studies in which subjects are typically asked to perform two tasks simultaneously. The performance in this dual task situation is compared to that of each of the individual tasks. Limitation is revealed by a decrement in the dual task performance relative to that of the individual tasks.

0612.012 Initial findings with this paradigm have led to two generalizations. First, performance in the dual task is generally poorer, indicating that the cognitive system is limited. Second, subjects can, upon instructions, prefer one task over another in a semicontinuous fashion. Subjects instructed to invest 50 percent, or 60 percent, or 70 percent, and so on in one of the tasks, perform progressively better in this task relative to the other. These generalizations are readily captured by a 'limited resources' theory, stating that people have a limited but flexible amount of cognitive resources (or energy). Dual task performance is limited because of limited resources: Two tasks cannot receive simultaneously the same amount of resources as individual tasks. Because the resources are flexible, their division among the tasks can vary, leading to a better performance in the task with the added resources.

0612.013 Later studies, however, revealed that a simple resources theory is not adequate. The main problem is that dual task performance is better when the two tasks are dissimilar to each other. For example, when the input to the two tasks is both auditory or both visual, performance is worse than when the inputs to the two tasks are visual and auditory respectively. To account for these and similar findings, the resource theory had to assume that there are several independent pools of resources, each of which is limited. When two tasks draw on the same pool of resources, performance is limited. The more the two tasks draw on different pools of resources, the less limited is the dual task performance. There are few studies in which no decrement in dual task performance was observed. The multiple resource theory explains these findings by stating that the tasks in these studies draw upon entirely different pools of resources. One persistent problem with this theory, however, is that it has proven impossible to identify the nature of the independent pools of resources.

Summary

0612.014 Although bottleneck and resource theories were primarily designed for focal and divided attention studies respectively, both were proposed as general accounts, and each theory was used as an explanation for both paradigms. Resources theories claim that the reduced processing of unattended messages is caused by allocation of fewer resources for this purpose. Bottleneck theories claim that decrements in dual task performance arise when both require a processing unit that can only be used for one task at a time.

The debate among the theories has not yet been 0612.015
settled. One difficulty is methodological: it turned out to be exceedingly difficult to control tightly the subjects' attention, a pre-requisite for an unambiguous interpretation of the findings. Another possible reason is that there may be more than one source of limitation (or selection) in the stream of processing. The next section addresses this latter possibility.

MULTIPLE LEVELS OF SELECTION

The models described so far assume a single select- 0612.016
ive attention mechanism. The early versus late selection debate concerns the locus of that single mechanism. The literature, however, suggests that there may be at least two distinct levels in which selection may take place, with distinct mechanisms operating in each of these levels. There is a high level selection used for strategic choices such as a preference of one task over another, or a shift from one task to another. It is often stated that strategic selection is performed by a set of processes called 'executive functions'. There is also a second, lower-level selection mechanism that may even be modality-specific.

Selection by executive functions

We are constantly facing strategic cognitive choices 0612.017
in our everyday life. At a larger scale we decide on the activities in which we want to be involved. At a smaller scale we are often faced with several possible tasks and need to decide which has a higher priority or when to shift from one task to another. For example, we can be engaged in driving, listening to the radio, and talking to a friend. We may decide to carry out all these activities simultaneously, but we often assign different priorities to the tasks, and can shift these priorities with changing conditions. The executive functions perform these control activities.

We focus on one paradigm, known as the psy- 0612.018
chological refractory period (PRP) paradigm, because it is relevant for the question concerning the locus of selection. In this paradigm subjects are required to perform two different tasks in succession. The input to the two tasks is presented in succession as well. Subjects respond to the two tasks as fast as possible with the constraint that the

response to one task (T1) is performed before the response to the second task (T2). The main manipulation is the temporal gap, called stimulus onset asynchrony (SOA), between the presentation of the inputs to T1 and T2. Subjects are usually able to conform to the instructions, presumably by the use of executive functions: the response to T1 is committed first, and is not affected by the SOA. The response to T2, however, is typically dramatically affected by the SOA. At very short SOAs (e.g. 50 milliseconds), response to T2 is very slow. With longer SOAs, response to T2 improves progressively. Around SOA of 300–400 milliseconds, the response becomes similar to that of T2 by itself.

0612.019 Why is the response to T2 affected by its temporal proximity to T1? Much evidence suggest that subjects do not assign stimuli to responses for two tasks simultaneously, a process called response selection. That is, while response selection is performed for T1, it cannot be done for T2. Instead, subjects 'wait' until response selection for T1 is complete and only then proceed to the response selection of T2.

0612.020 These findings led some researchers to suggest that a 'bottleneck' in the stream of processing occurs at the response selection stage. Others claim that this apparent bottleneck at the response selection stage is only a reflection of decisions by the executive functions to allocate all the resources to response selection of T1. In other words, both 'bottleneck' and 'resources' theories can explain these findings. Regardless, we see how selection of T1 in the expense of T2 is presumably done by selective attention mechanisms related to the executive functions.

Selection within modalities

0612.021 The preceding section showed how attention selects between tasks. Attention also selects within a single task, even when the task is exceedingly simple. We focus on the visual modality because most of the research in this domain used visual tasks. Selections also take place in other modalities.

0612.022 Imagine a task where you are required to make a single response to a stimulus when it appears inside one of two boxes located to your right and left. The location of the stimulus is not relevant to your response because the same response is required for the two locations. Much research suggests that if you are cued in advance that the target is likely to appear in one side, your response is faster when the target indeed appears in the cued location and is slower when the target appears in the other side, relative to situations with no cueing. The costs and benefits from the cueing are ascribed to the operation of visual attention. Attention operates by selecting the location (or the box) of the cued area, leading to facilitation in the response to targets within the selected area.

As in other phenomena of selection, there are disagreements concerning the locus in which attention affects processing. It could affect perception of the target, or it could affect response decisions for the target, or more resources are assigned to the selected area. Note that this selection is observed even for exceedingly simple tasks. There may be additional types of selection required for more complex task. These, however, are more controversial and will not be reviewed here. 0612.023

Relation between the two types of selection

The selection between two tasks, and the selection within a single task appear quite different. Indeed, there are behavioral and neuropsychological studies that support the separation of these two types of selection. Behaviorally, there is evidence that, although (as noted above) subjects in the PRP paradigm do not select responses to task 2 when performing task 1, they are able to shift their visual attention for task 2 during the performance of task 1. This suggests that response selection, done by the executive functions, and visual attention are distinct. Data from neurologically impaired patients and from imaging techniques suggest the existence of a posterior system of attention, presumably dedicated to lower-level selections (e.g. visual attention), and an anterior system dealing with executive functions. 0612.024

Further Reading

Duncan J (1980) The demonstration of capacity limitation. *Cognitive Psychology* **12**: 75–96.

Johnston JC, McCann RS and Remington RW (1995) Chronometric evidence for two types of attention. *Psychological Science* **6**: 365–369.

Kahneman D and Treisman AM (1984) Changing views of attention and automaticity. In: Parasuraman R and Davies DR (eds) *Varieties of Attention*, pp. 29–61. Orlando: Academic Press.

Lavie N (1995) Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance* **21**: 451–468.

Pashler (1998) *The Psychology of Attention*. Cambridge, MA: MIT Press.

Posner MI (1980) Orienting of attention. *Quarterly Journal of Experimental Psychology* **32**: 3–25.

Posner MI and Petersen SE (1990) The attention system of the human brain. *Annual Review of Neuroscience* **13**: 25–42.

Shiffrin RM (1988) Attention. In: Atkinson RC, Herrnstein RJ, Lindzay G and Luce RD (eds) *Steven's Handbook of Experimental Psychology: Volume 2, Learning and Cognition*, pp. 739–811. New York: John Wiley & Sons.

Shiffrin RM and Schneider W (1977) Controlled and automatic human information processing: II. perceptual learning, automatic attending, and a general theory. *Psychological Review* **87**: 127–190.

Yantis Y and Johnston JC (1990) On the locus of visual selection: evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception and Performance* **16**: 135–149.

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