other highly mobile, disadvantaged children without added resources.

Researchers have an important role to play in providing information to guide policy and evaluate programs. Although a number of studies have been conducted and more are under way, there are major gaps in the knowledge base. Little is known about the processes leading to or out of homelessness or the factors that ameliorate risk and facilitate better outcomes for children and their families. Most studies include heterogeneous samples of homeless families that differ markedly in background and current status on many dimensions that may be crucial for understanding causes and outcomes and for developing strategies to reduce the risks of becoming homeless or ameliorate its effects on parents and children. There is also a great need for information on the welfare of unaccompanied minors and how homeless runaways and abandoned children differ from or resemble homeless adolescents who stay with their families.

In addition, there is a profound shortage of normative data on the development of ethnic minority children and of appropriately standardized measures for use with low-income or minority children. Normative data on the development of ethnically and socioeconomically diverse populations of children would provide the context for understanding developmental problems among homeless and other high-risk populations.

Finally, it is clear that isolated efforts, whether in the domain of research, policy, or intervention, limited to one place, one discipline, or one perspective, are inadequate to meaningfully address the complex problem of homeless children. Coordinated, multifaceted efforts are required at each level in each domain of inquiry and action. Helping homeless children and preventing homelessness may also depend on national acceptance of the idea that poor children belong to all of us. Certainly, their development will affect all of our futures.

Acknowledgments—Support for the author's research on homeless children, partially described in this article, was provided by a McKnight Professorship and a Graduate School Grant-in-Aid award from the University of Minnesota.

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Attentional Limitations in Doing Two Tasks at the Same Time

Harold Pashler

Beginning with the work of Sherrington near the turn of the century, it has emerged that the basic units of the nervous system—the neurons—operate in parallel, with hundreds of millions of neurons firing away simultaneously. But what about *mental operations?* Can we carry out more than one distinct mental operation in parallel? Or are certain psychological processes restricted to operating one at a time? This article describes some recent experimental studies of what happens when individuals attempt to carry out more than one activity at the same time. The focus is on simple tasks for which the time-course of processing can be analyzed in detail. The results are beginning to reveal something of the underlying processing limitations of the mind and imply surprisingly severe and stubborn limits on what mental activities people can accomplish at the same time. The results also suggest that speaking of attention as a single mental resource or capacity is misleading, because several quite distinct processing limitations exist,

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each of which—in its own way—restricts our ability to carry out more than one task at a time.

People are generally aware of difficulty doing two things at the same time only when the tasks are cognitively demanding. Laboratory evidence, however, reveals that even the very simplest activities suffer interference when undertaken close together in time. For example, in the 1940s, Welford[1] required people to perform two reaction time tasks, each requiring a speeded response to a separate stimulus. The response time (RT) to the second stimulus was always increased when the interval between the stimuli was shortened (Fig. 1).

This interference—usually termed the *psychological refractory effect*—is sizable and robust. The effect occurs when each task is extremely simple, such as naming a word or pressing one of two buttons depending on the pitch of a tone. It occurs even when the stimuli are not in the same sensory modality, and investigators have found such interference with diverse combinations of responses, including speech and movements of the hands, feet, and eyes. It has also been observed that thousands of trials of practice do not generally abolish the interference. Why should people experience such difficulty in doing two seemingly trivial activities at the same time?

Welford proposed the existence of a *bottleneck* in the process of choosing and selecting an action in each task. In this view (as shown in Fig. 2), during the time while the first response is being selected, the selection of the second response is held up (although perception of the second stimulus can proceed as soon as the stimulus is present). The most natural explanation for such a bottleneck would be that some single mental mechanism is necessary for carrying out response selection (somewhat akin to a central processing unit in a digital computer). However, evidence for Welford's proposal was indirect, and there was little consensus.[2] Many alternative theories proliferated in the 1960s and early 1970s (especially the idea of *attentional resources,* which, it was proposed, were divided up between the two tasks). Over the following years, the study of dual-task

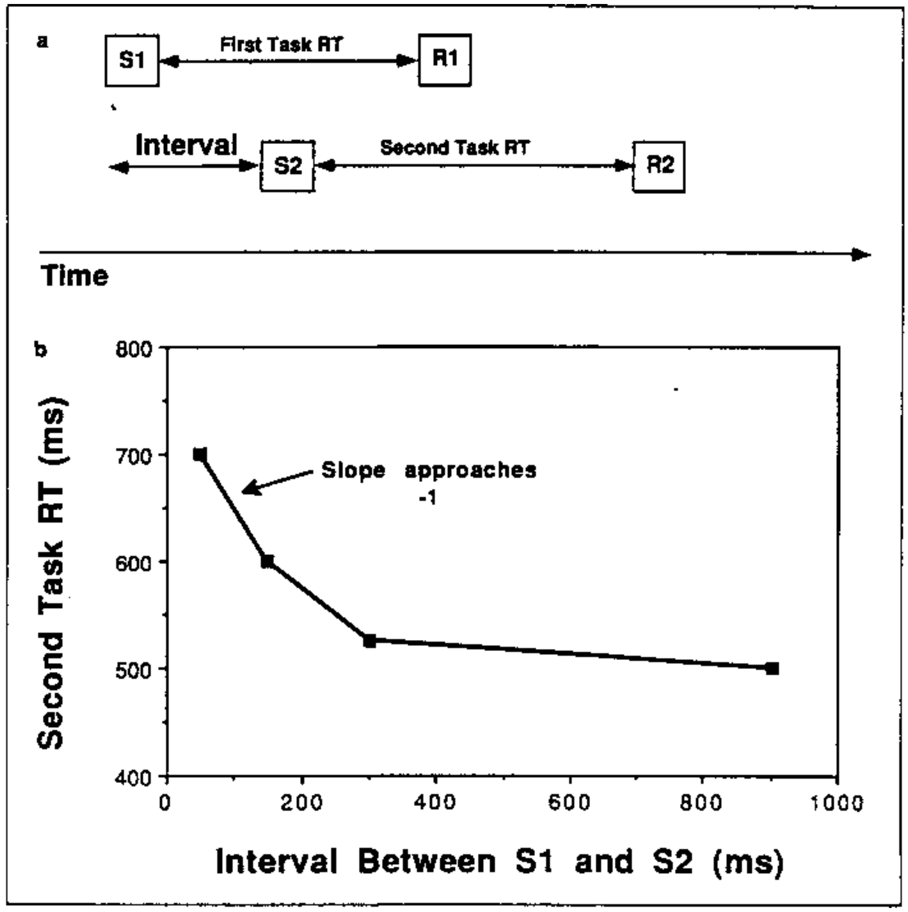

Fig. 1. (a) The timing of a dual-task (psychological refractory period) experiment. The first stimulus (S1) is presented, followed by the second stimulus (S2), after a variable interval. The subject responds to each (R1 and R2, respectively). The RT for each task is measured from stimulus to corresponding response, (b) Typical result in a dual-task experiment: As the interval is shortened, the RT for the second task increases. When the interval between the stimuli is short, the slope frequently reaches - 1.

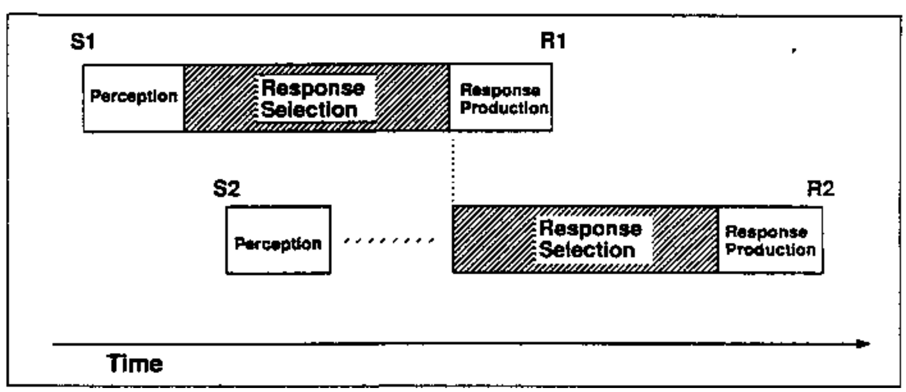

Fig. 2. The response selection bottleneck model. The selection of the two responses cannot occur at the same time; therefore, the second response selection waits for completion of the first response selection. Perception and response production are not subject to such limitations.

interference in simple tasks fell into neglect.

EVIDENCE FOR A BOTTLENECK

Over the past few years, we have been examining these dual-task interference effects anew. Converging evidence from my laboratory (and that of James C. Johnston, at the Ames Research Center, National Aeronautics and Space Administration) makes a strong case that Welford was correct in postulating a response selection bottleneck. In many of our experiments, we vary the duration of particular stages of processing in dual-task experiments. For example, if the second task requires a speeded response to a letter, the intensity of the letter may be reduced, to slow the perception of the letter. In other cases, the process of selecting the second response may be slowed, by varying the difficulty of the *mapping* from stimuli to responses, while keeping the stimuli and responses the same. For example, with three response keys laid out in a row in front of the subject, the subject might be instructed to press the left, middle, or right response key when the stimulus is a 1, 2, or 3, respectively; this would be the easy mapping condition. In the *difficult* mapping condition, the same keys would be pressed when the stimulus is a 2, 3, or 1, respectively.

The bottleneck model makes detailed and sometimes counterintuitive predictions about how such manipulations ought to affect RTs in each task. Consider an analogy. If you walk into an empty bank (which has only one teller on duty) just after Ms. Jones enters the bank, the teller represents a bottleneck: He must finish with Jones before you can be served. Therefore, whether you walk quickly or slowly up to wait for the teller will not affect how much time you will spend in the bank. For the same reason, slowing the perceptual processing in the second task should not slow the second task RTs when the interval between the two stimuli is very short; the selection of the second response will generally be waiting for the selection of the first response, not for the perception of the second stimulus.

To return to the bank analogy, if you take some extra time to talk with the teller, this obviously *will* increase the time you spend in the bank. For the same reason, when response selection is slowed by changing the stimulus-response mapping in the second task, the bottleneck model predicts this change should have the same (full) effect on the second task RTs, whatever the interval. These and related predictions from the model shown in Figure 2 have been tested and confirmed in various experiments.[3]

The bottleneck model also correctly predicts that when the time needed for selecting the first response is increased, the RT for the second task increases accordingly (with the slowing varying inversely with the interval between the stimuli). (To return to the analogy, if Jones takes extra time with the teller, this holds up not only her, but you as well.) Furthermore, if the bottleneck model is correct in asserting that the perception of the second stimulus is not delayed by processing in the first task, then a person should be able to perceive (and later report) a very brief visual display that is presented while the person is carrying out a task requiring immediate response to a tone. This prediction has been confirmed.[4] Additional support for the model comes from examining the correlations across trials between the RTs in the two tasks.[4]

Why should the mental operation of choosing a response—in such apparently trivial tasks—be so demanding as to constitute a bottleneck in processing? The problem is not in producing the motor actions per se: When the response in the first task involves a sequence of responses, adding more movements to the response sequence may add a half second or more to the time needed to complete the first task response, but does *not* delay the second task RT to this extent.[5] (To belabor the Ms. Jones analogy a bit more, if Jones lingers in the bank to count her money, but is considerate enough to do so after leaving the teller to handle you, this holds her up, but not you!)

In summary, converging chronometric results show that in the dual-task situation, the selection of the second task response waits for the selection of the first task response, but not for the production of the response. The problem is cognitive, not motoric. Thus, it is not surprising that producing the same action over and over (e.g., repetitive finger tapping) produces very minimal interference with most concurrent tasks (except those that involve production of an incompatible rhythm). When there is no response uncertainty, people have no trouble doing two different tasks at the same time.

EXTENT OF THE BOTTLENECK

Does a separate response decision occur prior to every individual movement that a person makes? Fagot and I recently examined what happens when a single input determines two distinct responses. In one such experiment, subjects were told to name aloud the color of a stimulus patch and also to press one of several response keys depending on the color of the patch. We found very little delay in either response, compared with the case when each task was performed alone.[6] Various analyses showed that only a *single* response selection was occurring, but this single selection yielded a response *couplet,* consisting of both the naming and the key press. It seems likely that outside the laboratory, people select coupled responses all the time, avoiding the need to make separate response choices in series.

The results described thus far reveal an inability to retrieve from memory more than one response at a time. Of course, in the cases I have been discussing, the retrieval is so trivial that one would not normally think of memory being involved at all. What about the sort of effortful recall that one normally thinks of as memory retrieval? Is it subject to the same bottleneck? Some recent studies by Carrier and myself have combined more time-consuming recall tasks, such as cued recall from a list of paired associates (e.g., "FISH-29"), with reaction time tasks. It seems that carrying out a reaction time task involving key-press responses to tones prevents people from carrying out a difficult cued recall from memory.[7] This finding suggests that the bottleneck first proposed by Welford to account for effects involving almost "reflexlike" reaction time tasks also crops up when people try to carry out higher mental processes such as memory retrieval.

SUBDIVIDING ATTENTION

Laypersons and psychologists alike often use the term *attention* in speaking of the difficulties people experience in carrying out more than one activity at the same time. This term is, of course, also applied to the mechanisms that allow people to select—for further processing and awareness—one particular stimulus from among the barrage of sensory inputs at any one moment. Are these phenomena really reflections of a single system? One approach I have taken to answering this question has been to see whether response selection in one task can be carried out while a shift in spatial attention is occurring in another task. One set of studies combined a speeded task with a second (unspeeded) visual task that required an attention shift. For example, in one of the experiments, the first task involved a button-press response to a tone, and the second task involved (unspeeded) report of the character to which an arrow pointed in a brief visual display. To determine which character the arrow was pointing to, the subjects needed to shift their attention immediately, before the display was replaced with a mask. The data showed that subjects were able to do this while carrying out the unrelated tone task. Thus, there was no evidence that the selection of the response to the tone delayed the shift of attention.[8]

Further evidence for the distinction between sensory attention mechanisms and the bottleneck described here is provided by studies of perception of multiple sensory dimensions. Duncan has observed that people are much more accurate in perceiving two attributes (e.g., color and form) in a briefly flashed display when the attributes are part of the same object than when they are part of two different objects.[9] But Fagot and I found that when people make a separate speeded response to each of the two attributes, the second response is delayed; the same amount of delay is present whether the two attributes are in the same object or not.[6] Thus, the response selection bottleneck seems to be indifferent to whether its inputs originate from the same perceptual object or different objects, a factor that affects spatial attention a great deal.

It would seem, therefore, that it is misleading to use the term attention to refer to the limitations people have in carrying out concurrent response selections and memory retrievals, on the one hand, and to the limitations arising in selecting and processing sensory stimuli, on the other hand. Posner, Inhoff, Friedrich, and Cohen[10] have suggested that distinct control functions may be carried out in anatomically separate brain systems: an "anterior attentional system" controlling action and a cortical "posterior attentional system" controlling sensory gating. The neural basis for the sequential selection of actions is unknown, but new evidence hints it may depend heavily on subcortical pathways. Several split-brain patients were recently tested with two concurrent tasks. The sensory input and motor output were lateralized to different hemispheres, by requiring a left-hand finger response to a stimulus in the left visual field in one task and a right-hand finger response to a right visual field stimulus in the other task. So far, it appears that these patients show the same pattern of interference as normal controls.[11] Thus, it seems that some subcortical circuit may control the bottleneck. Nonetheless, cortical activity involved in selecting responses is delayed in the dual-task paradigm, as Osman and his colleagues showed in a recent study recording scalp electrical potentials over the motor cortex in a dual-task experiment.[12] One possible interpretation is that response selection occurs in the cortex, but once one such process is under way, a subcortical circuit inhibits other such processes.

DISCUSSION

The results described here pose an intriguing question. On the one hand, laboratory studies indicate people have a stubborn inability to carry out certain components of even the very simplest tasks simultaneously. On the other hand, most people report that they routinely carry out two complex activities (such as driving and having a conversation) at the same time. It is commonly supposed, by psychologists and laypersons alike, that this occurs because one or both of the activities have become "automatized" through practice, thereby ceasing to require "mental capacity." The effects of long-term practice have not been adequately studied, but the results that do exist suggest that when it comes to selecting responses, practice does not readily eliminate the fundamental bottleneck. There are other factors that seem more likely to account for the discrepancy between the laboratory results and our everyday intuitions. For one thing, activities like driving involve selection of actions only intermittently. Some of the time that one is having a conversation, one may be producing preplanned sequences rather than choosing new ones; at these moments, the bottleneck is presumably freed up for other tasks. Finally, when delays on the order of hundreds of milliseconds do occur, they may simply go unnoticed, and the conversation is resumed, with short-term memory smoothly bridging the gap.

Of course, further research will be needed to reveal more about the underlying causes of human limitations in information processing, and the relevance of these limitations to ordinary experience. Studies of the timing of processing stages in simple tasks performed concurrently seem likely to offer further empirical clues about the functional architecture of the mind.

Acknowledgments—-The author acknowledges the vaulable technical assistance of Alann Lopes and support from NIMH (1-R29-MH45584-01), NASA Ames (Inter-changes NCA2-225 and NCA2-414), and ONR (N00014-88-K-0281).

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Navigation of a Small Mammal by Dead Reckoning and Local Cues

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A sedentary animal who leaves its "home" in search of particular resources must return. Even a young and inexperienced subject may determine and maintain an indication of the direction and distance home during short exploratory excursions.

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All it has to do is to keep track of its outward journey, either by signals that are entirely self-generated during locomotion or with a directional reference from the environment, such as the sun. If the information of homeward direction and distance is maintained by a continuous integration (summing) of moment-to-moment changes to produce a moment-to-moment indication of the animal's position relative to home, then the animal may return along the shortest path. Homing strategies that depend on this type of route-based information processing have been described mainly by ethologists for a number of arthropods and vertebrates under the name of dead reckoning, vector *navigation,* or path *integration.*[1,2]

In contrast, many species associate stable local cues or landmarks with particular locations on a long-term basis and thus rely on specific features of the familiar environment to navigate from one place to another. Provided these associations are connected by a general representation of familiar space—the so-called cognitive map—they allow a subject to proceed from place to place according to a set of well-established transformation rules. This kind of navigation is called *piloting.*

Piloting and dead reckoning have