5. I. Abramov, *J. Opt. Soc. Am.* **58**, 574 (1968); F. M. DeMonasterio, P. Gouras, D. J. Tolhurst, *J. Physiol. (London)* **251**, 197 (1975); R. L. DeValois, D. M. Snodderly, Jr., E. W. Yund, N. K. Hepler, *Sens. Processes* **1**, 244 (1977).
6. J. Krauskopf, *J. Opt. Soc. Am.* **53**, 741 (1963).
7. G. L. Walls, *Am. J. Optom.* **31**, 329 (1954).
8. H. D. Crane and C. M. Steele, *Appl. Opt.* **17**, 591 (1978).
9. H. D. Crane and M. R. Clark, *ibid.*, p. 706.
10. H. J. M. Gerrits, B. DeHaan, A. J. H. Vendrik, *Vision Res.* **6**, 427 (1966).
11. H. J. M. Gerrits and G. J. M. E. N. Timmerman, *ibid.* **9**, 439 (1969).
12. This work was supported by NIH grant EY01031 awarded by the National Eye Institute and by Office of Naval Research contract N00014-79-C-0742.

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Performance of Concurrent Tasks: A Psychophysiological Analysis of the Reciprocity of Information-Processing Resources

Abstract. *The resources allocated to a primary and secondary task are reciprocal. Subjects performed a tracking task in which the discrete displacements of the tracking cursor could be used to elicit event-related brain potentials. As the resource demands of the tracking task were increased, potentials elicited by the task-defined events increased in amplitude, whereas those elicited by secondary task auditory stimuli decreased.*

The limitations on the capacity of the human information-processing system have long been recognized. When the human mind is occupied with one task it often lacks the capacity to perform others. Under some circumstances, however, many tasks can be performed concurrently. Much ingenuity has been devoted to defining the limits of processing capacity and to elucidating the way capacity varies under different conditions to influence the success of dual task performance. In a conceptualization that owes much to Kahneman (*1*) and that has been developed by others (*2–4*), performance of a task is assumed to consume resources that are in limited supply. The degree to which two tasks interfere with each other depends on the extent to which they compete for the common supply of resources.

Any attempt to study the limitation on the human capacity for time-sharing must contend with the impossibility of assessing resources directly. Furthermore, resources cannot be inferred from the quality of task performance: performance can remain constant in quality despite changes in the demands on the operator. To overcome these difficulties, a frequently used technique for measuring resource allocation is to assign to the operator yet another, secondary, task that must be executed concurrently with the primary task. The operator is instructed to perform the primary task in the best possible manner and the secondary task as well as possible under the circumstances. Performance of the secondary task is used to assess the resource demands imposed by the primary task (*5*).

In a series of investigations, Donchin, Wickens, and their co-workers have established that the amplitude of the P300 component of the human event related potential (ERP) can serve as a secondary task measure of the resource demands of a primary task (*6*). To subjects who were performing a variety of complex tasks they presented a concurrent Bernoulli sequence of stimuli with unequal probabilities. If such a sequence is attended, the rare stimulus elicits a P300 whose magnitude is inversely related to the probability of the eliciting event (*7*). When this secondary task is performed concurrently with a primary task, the amplitude of the P300 elicited by the rare stimuli depends on the difficulty of the primary task, provided that difficulty is manipulated in the perceptual-cognitive domain.

These data suggested that the amplitude of the P300 can serve as an index of the resources available to the operator from a primary task. This hypothesis implies that when the primary and secondary tasks tap common resources there is a reciprocity in the availability of these common resources to the primary and the secondary task. As a consequence, there will be a reciprocity in the amplitude of the P300 associated with the two tasks as the difficulty of the primary task is varied. In other words, while P300 associated with the secondary task decreases in amplitude with increasing difficulty of the primary task, it should be possible to observe a corresponding increase in the amplitude of the P300 elicited by stimuli associated with the primary task (*8*).

Twelve right-handed students (eight males and four females), performed a pursuit step-tracking task. A target executed a series of discrete horizontal displacements, the magnitudes of which were determined by a random process. The displacements occurred at 3-second intervals. The subjects manipulated a control stick and attempted to superimpose a cursor on the target. Changes in the difficulty of the task were accomplished by manipulating two variables. (i) The directional regularity of the sequence of the step changes had two levels. Under the condition of high predictability, the step displacements alternated in a regular left-right sequence. Only the magnitude of the step change remained unpredictable. Under the condition of low predictability, both magnitude and direction were uncertain so that two successive steps in the same direction were possible. (ii) The relationship between the movement of the joy stick and the movement of the cursor was varied. When the subject had first-order control, constant displacement of the control stick caused the cursor to move at a constant velocity in the direction of the movement. Under the more difficult second-order control conditions, constant movement of the stick accelerated the cursor's movement. These two manipulations were combined to create three conditions of increasing difficulty: First-order control with predictable input (1P), first-order control with unpredictable input (1U), and second-order control with unpredictable input (2U) (*9*).

Concurrently with the tracking tasks, the subjects were assigned one of three secondary tasks designed to elicit the ERP's (*10*). Two of these were clearly secondary, whereas stimuli for the third were embedded in the primary task itself. (i) Auditory probe: subjects heard a Bernoulli series of tones of high and low pitch, occurring with equal probability. Subjects were instructed to count the number of occurrences of the low-pitched tone. (ii) Visual probe, flash: a horizontal bar was imposed along the course traversed by the target. The bar was flashed for 100 msec. On a randomly selected half of the trials the flashes were brighter than on the other trials; the subject was instructed to count the dimmer flashes. (iii) Visual probe, step: subjects counted all steps in which the target moved in a given direction; the probes eliciting the P300 were embedded in the primary task. In an additional control condition subjects tracked the step changes in the absence of a secondary task. In the control condition and in the visual probe step condition, the averaging computer was triggered by the step changes so that ERP's elicited by the change in the target's direction were recorded. Finally, three additional conditions were included in which each of the three secondary counting tasks (auditory probe, visual probe flash, visual probe step) was performed without the concurrent tracking task, though the moving target remained on the screen (*11*). After performing each task, subjects were asked to rate, on a seven-point scale, the subjective difficulty of the task just performed.

The primary tasks presented the subject with an increasingly greater challenge. The tracking error (*12*) was lowest in the 1P condition and greatest in the 2U condition (Fig. 1A). The primary and secondary tasks interacted in that the root-mean-square error was larger when the counting task was performed. The subject's experience was consistent with the order of difficulty indicated by the tracking errors (Fig. 1B) (*13*).

The average waveforms and base-to-peak measure of P300 amplitude for ERP's recorded at the parietal electrodes are shown in Figs. 2 and 3. Data were analyzed statistically by submitting the digitized waveforms to four principal component analyses (PCA's) (*14*)—one each for the auditory, visual flash, and the two visual step conditions. Separate analyses were made necessary by variability in the latency of the P300 component across experimental conditions. The solid line in Fig. 3, representing the ERP's elicited by auditory probes, replicates previously reported results in similar studies (*6*). In general, a large P300 was elicited by the counted event when counting was the subject's sole assignment (Figs. 2 and 3). The introduction of a concurrent tracking task led to a substantial reduction in the P300 amplitude, which was further reduced with increasing difficulty of the primary task. The reduction in P300 amplitude cannot be attributed to the subjects' failure to count probes during the more difficult dual-task conditions, since the counting accuracy remained uniformly high across experimental conditions and manipulations of difficulty.

The amplitude of the P300 in the two visual probe conditions (Fig. 2, B and C, and Fig. 3) was also significantly attenuated by the introduction of the tracking task. This decrement or "cost of concurrence" (*2*) results from reallocation of a certain portion of resources from the count task to the tracking task, independent of the probes used in the former or the difficulty of the latter. In the visual flash condition, increases in primary task difficulty failed to produce any further attenuation (*15*). In both the step probe and control conditions, (Fig. 2, C and D, and Fig. 3), increasing the resources demanded by the primary task resulted in a concomitant enhancement in the amplitude of the P300 elicited by primary task stimuli. All of the difficulty levels were significantly different from each other in the visual step and control conditions.

These results provide additional support for the hypothesis that the reduction in the amplitude of the P300 elicited by the stimuli of secondary tasks results from a depletion of the resources deployed in the service of the secondary task by competition for these resources from the primary task. As predicted, when the probe stimuli are embedded within the primary tracking task, these stimuli elicit P300's with increasing magnitude as tracking difficulty increases. Hence, the concept of resource allocation, normally an inferred construct based on changes in primary task difficulty and secondary task performance, is validated by our data. This validity results from the observation of the reciprocal change in P300 between the auditory and the embedded probes as difficulty is varied. In interpreting the functional role of the resources that underlie changes in

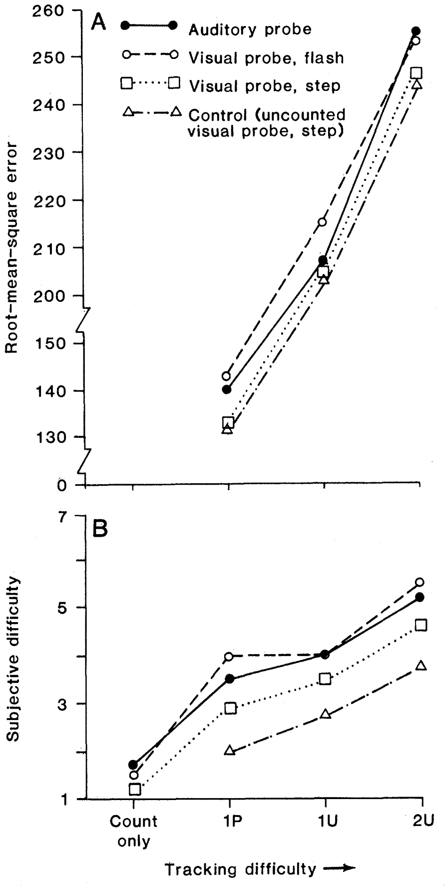

Fig. 1. Average root-mean-square error (A) and subjective difficulty ratings (B) recorded for each of the experimental conditions.

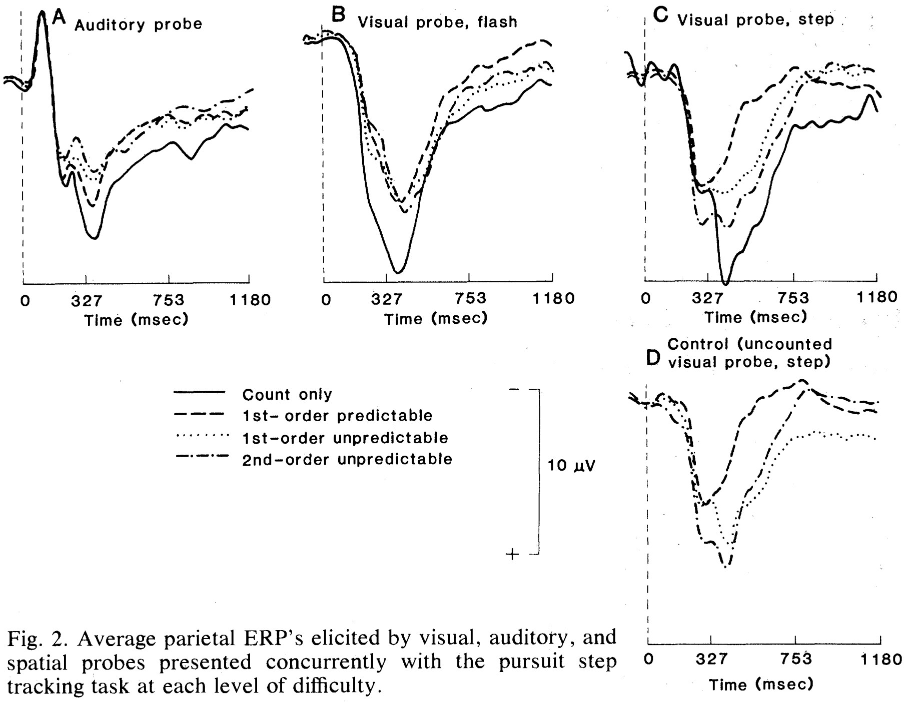

Fig. 2. Average parietal ERP's elicited by visual, auditory, and spatial probes presented concurrently with the pursuit step tracking task at each level of difficulty.

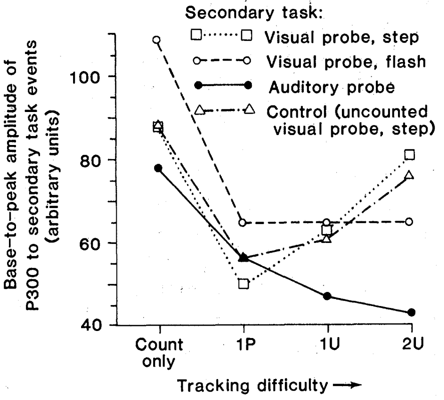

Fig. 3. Normalized base-to-peak measure of P300 amplitude for each experimental condition.

P300 amplitude, we assume that the P300 manifests the activation of some information processing activity that is invoked by the appearance of task-relevant events, its amplitude inversely related to its expectancy. It has been suggested that this "subroutine" is involved in updating, or revising, the model of the environment maintained in working memory (*16*). The resources on which this updating activity depends seem to be limited in their availability, and, when deployed in the service of one task, their availability to be of service to other tasks is reduced.

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References and Notes

1. D. Kahneman, *Attention and Effort* (Prentice Hall, Englewood Cliffs, N.J., 1973).
2. D. Navon and D. Gopher, *Psychol. Rev.* **86**, 214 (1979).
3. D. A. Norman and D. G. Bobrow, *Cognit. Psychol.* **7**, 44 (1975).
4. C. D. Wickens, in *Attention and Performance*, R. Nickerson and R. Pew, Eds. (Erlbaum, Englewood Cliffs, N.J., 1980).
5. G. D. Ogden, J. W. Levine, E. J. Eisner, *Human Factors* **21**, 529 (1979).
6. For example, J. B. Isreal, C. D. Wickens, G. L. Chesney, E. Donchin, *ibid.* **22**, 211 (1980).
7. E. Donchin, W. Ritter, W. C. McCallum, in *Event-Related Brain Potentials in Man*, E. Callaway, P. Tueting, S. H. Koslow, Eds. (Academic Press, New York, 1978).
8. Some investigators [for example, E. Spelke, W. Hirst, O. Neisser, *Cognition* **4**, 215 (1976)] have questioned the extent to which resources truly are "fixed," in quantity, or whether in fact these may "expand" with increases in task difficulty (*1*). As long as it is assumed that any expansion in supply is insufficient to compensate entirely for increased demands, we argue that the concept of reciprocity of primary and secondary task resources remains valid—secondary task resources will be less available as primary task demand increases.
9. Assuming the framework that resources are multidimensional (*2, 4*), we have chosen manipulations of tracking difficulty that impose demands on the same perceptual-cognitive resources that are assumed to underlie the processes manifest in P300 elicited by either auditory or visual stimuli (*6*). Hence, increasing the order of tracking control requires perception of higher derivatives of the error to maintain effective performance [C. D. Wickens *et al.*, *Proceedings of the 17th Annual NASA Conference on Manual Control*, NASA Technical Manual, 1981). Decreasing input predictability similarly demands greater perceptual anticipation.
10. The electroencephalogram (EEG) was recorded from three midline sites (Fz, Cz, and Pz according to the 10-20 system) and referred to linked mastoids. The vertical electro-oculogram (EOG) was recorded by placing one electrode below and one above the left eye. Two ground electrodes were positioned on the left side of the forehead. Electrode impedances did not exceed 5 kohm/cm. The EEG and EOG were amplified with amplifiers (Van Gogh model 50000) (time constant, 10 seconds; upper half-amplitude, 35 Hz; roll-off, 3 dB per octave). Both EEG and EOG were sampled for 1280 msec, beginning 100 msec before stimulus onset. The data were digitized every 10 msec. The ERP's were filtered off-line (−3 dB at 6.29 Hz and 0 dB at 14.29 Hz) before statistical analysis.
11. Subjects participated in two experimental sessions. The first consisted of 30 blocks of practice trials, 10 with first-order control dynamics and 20 with second-order control dynamics. In session 2, subjects performed two practice blocks (first- and second-order) before participating under experimental conditions. The 30 experimental blocks were composed of two replications of the 15 conditions (four difficulty manipulations by three secondary tasks and three single-task tracking blocks). The order of presentation of the conditions was counterbalanced across subjects.
12. The root-mean-square error means for the three difficulty conditions (1P, 1U, and 2U) were 137, 208, and 249 [$F(2, 22) = 289.7$, $P < 0.0001$; paired contrasts between adjacent levels, $P < 0.01$ in both cases]. The interaction between experimental condition and primary task difficulty was also statistically significant [$F(6, 66) = 9.5$, $P < 0.001$].
13. The means for the subjective difficulty ratings in the count-only, 1P, 1U, and 2U conditions were 1.46, 3.07, 3.54, and 4.71 [$F(3, 33) = 99.2$, $P < 0.0001$].
14. The data bases submitted to the PCA's were composed of 288 average waveforms (12 subjects by four primary task difficulty manipulations by two stimuli by three electrodes) containing 128 (1.28-second) points each. Five components were derived from each PCA. The component scores obtained from the PCA's were analyzed in repeated-measures analyses of variance. All analyses were repeated after the single trial waveforms within each condition had been adjusted for differences in latency. This was accomplished to ensure that lower amplitude of the averaged waveform in certain conditions did not result from increased variability in latency. In all cases the analyses on the latency-adjusted waveforms showed the same statistical effects as on the unadjusted waveforms. Hence, we believe our effects are the result of true P300 amplitude changes and not changes in latency variability.
15. The reason P300 did not decline with tracking difficulty in the visual flash condition cannot be stated with certainty, although lack of a difficulty effect on secondary task visual P300's is consistent with the results of another unpublished study in our laboratory. We propose two hypotheses. (i) Tracking error is higher in the flash than in the auditory probe condition. Given the competition for the two tasks for visual input, subjects may have biased their allocation of resources toward the probes to a greater extent when the probes were visual than when they were auditory. (ii) The visual flash condition may be placed in the middle of an ordered continuum defining the degree of separation between primary and secondary task stimuli. Like the step probes, the visual flash probes share the common visual modality and spatial location; but like the auditory probes, they are independent events from stimuli in the tracking task. Since the step probes produce increasing amplitude with primary task difficulty and the auditory probes a decreasing amplitude, the visual flash probes, in the middle of this continuum, might reflect the compromise of these two trends, that is, no effect.
16. E. Donchin, *Psychophysiology* **18**, 493 (1981).
17. This research was supported by the Air Force Office of Scientific Research under contract F49620-79-C-0233 with Dr. Alfred Fregley as technical monitor.

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Lewy Bodies of Parkinson's Disease Contain Neurofilament Antigens

Abstract. *The Lewy body, a histological hallmark of Parkinson's disease, is a filamentous inclusion residing most prominently in pigmented neurons of the brainstem. Immunocytochemical reactions of Lewy bodies were examined with antisera to several filamentous proteins of the nervous system and positive reactions were found with those against neurofilaments. An abnormal organization of the neuronal cytoskeleton may be a pathological feature of Parkinson's disease.*

Parkinson's disease (PD) is a progressive, neurodegenerative disorder characterized by dysfunction in tone, movement, and posture. Decreased dopamine levels in the nigrostriatal pathway have been observed in PD (*1*). Since the dopamine deficit is accompanied by a loss of neurons in the substantia nigra (*2*), it is likely that neurotransmitter losses are secondary to neuronal death. It is therefore important to identify abnormalities of neuronal form and function in addition to neurotransmitter decreases. In this report we present evidence for a marked disorganization of the neuronal cytoskeletal system in neurons of PD by demonstrating that the Lewy body, a histological hallmark of idiopathic PD, contains neurofilament antigens.

Lewy bodies are intraneuronal, cytoplasmic inclusions that were originally described in neurons of the substantia innominata and dorsal motor nucleus of the vagus (*3*). They have since been found in neurons of the substantia nigra and other brainstem nuclei (particularly those that are aminergic) and in the hypothalamus, spinal cord, sympathetic ganglia, and, rarely, the cerebral cortex (*2, 4*). Although Lewy bodies have been recognized for many years by neurologists and neuropathologists, nothing has been known about their molecular composition, save that histological reactions have implied a proteinaceous nature (*5*). Since they represent an abnormality that accompanies neuronal loss in a major neurodegenerative disease, the identification of their components may help to illuminate the details of abnormal nerve cell metabolism.

Ultrastructural studies have demonstrated that Lewy bodies are composed of filamentous structures. At the periphery the filaments emerge radially, often admixed with granular or vesicular material. The denser core is composed of apparently random, tightly packed aggregations of filaments, vesicular profiles, and poorly resolved granular material (*6, 7*). The diameter of the filaments has been given as 7 to 8 nm (*6, 7*), a size commensurate with that of intermediate filaments, which are polymeric organelles composed of a class of acidic proteins found in a wide variety of cell types (*8*). The intermediate filaments of neurons, neurofilaments, seem to be pecu-