turned the gaze to F (Fig. 1b). A saccade to a visual target at location A (15° directly above F) is shown in Fig. 1c. If a saccade to S is induced by electrical stimulation just before the visually elicited saccade, a retinocentric model of the saccadic system would predict that the 15° upward saccade should still occur, causing a saccade from point S to A' (Fig. 1a). In the course of more than 10,000 trials at 29 stimulation sites, this result was never obtained. Instead, the stimulation-induced saccade was followed by a short-latency saccade from point S directly to location A (Fig. 1d).

Although there was often a period of 40 to 80 msec between the end of a stimulation-induced saccade and the beginning of the saccade to the location of the target, it was possible to time the stimulation so that the saccade to the target location immediately followed the stimulation-induced saccade. On other trials, the electrical stimulation interrupted the visually elicited saccade (Fig. 2). Except for the fixation and target spots, the room was in total darkness. For this series of trials, the visual target was 15° to the right of the initial fixation point. A visually elicited saccade to this target is seen in Fig. 2a. Electrical stimulation of a site in the right superior colliculus drives the eyes downward and to the left (Fig. 2b). Since fixation was not required during this stimulation trial, the eyes did not return to the original position.

Figure 2c shows a trial in which a saccade to the location of the visual target occurred immediately after a stimulation-induced saccade. Since the amplitude of the stimulation-induced saccade in Fig. 2c is smaller than that in Fig. 2b, the saccade to the visual target location may have interrupted the stimulation-induced saccade. Nonetheless, a saccade brought the gaze to the target location. Figure 2d shows a visually elicited saccade interrupted in midflight by a stimulation-induced saccade. Regardless of the point in space to which stimulation drove gaze, an accurate, short-latency saccade to the position of the target was made.

These results have implications for models of the saccadic system. Saccades to the actual target positions on stimulation trials (Figs. 1d and 2, c and d) could not have been directed by retinal error alone since all targets were turned off before any saccade. Since the occurrence of electrical stimulation on any trial was unpredictable, the compensation for the stimulation-induced saccade could not be determined in advance. Targets were not localized in space with respect to some visual frame of reference, since localization was about as accurate in the dark as in the light. It follows, then, that saccades directed to the positions of targets in space must have been localized by combining retinal error with an extraretinal eye position (*14*) signal. Since the compensation for eye position is precise even when visually elicited saccades are interrupted in midflight (*15*), the eye position signal must be derived from the accomplished rather than intended movement. That monkeys can localize targets accurately after saccades induced by stimulation of the superior colliculus indicates that the eye-position signal is derived from a point efferent from the colliculus.

Thus, our results are compatible with the spatial view of the saccadic system proposed by Hallett and Lightstone (*6*), Robinson (*4*), and Zee *et al.* (*7*). Saccades bring the eyes to a predetermined position in the orbit (or space) and do not drive the eyes a predetermined distance and direction.

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16. We thank S. Marcus and C. Horton for technical assistance and R. Sheetz for computer programs. Supported by NIH grants R01 EY01189, R01 EY02293, and P30 EY03039.

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Synthesis of the Contingent Negative Variation Brain Potential from Noncontingent Stimulus and Motor Elements

Abstract. *Slow shifts in brain potential (commonly called the contingent negative variation), obtained during a warned reaction-time task with a foreperiod of 1 second, were compared with waveforms synthesized by the addition of separately obtained potentials associated with individual (nonpaired) sensory stimuli and self-initiated motor movements. The synthesized waveforms match closely the actual contingent negative variation, suggesting that it is constituted largely of separate, noncontingent elements related to sensory and motor processes.*

The contingent negative variation (CNV) is a negative shift in brain potential that develops during the foreperiod between a warning stimulus (S1) and a subsequent imperative stimulus (S2) commanding a mental or motor response (*1*). It has usually been held to reflect expectation and preparation during the foreperiod, and as such has been considered to be a physiological index of mental activity. Recent findings suggest that the CNV may represent an admixture of two or more waves that are seen in combination when recorded at the traditional short foreperiod of 1 or 2 seconds. Some evidence for this may be adduced from variations in the appearance of the CNV brought about by changes in the task, motor response, or recording site (*2–4*). Additional evidence comes from situa-

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tions in which the foreperiod is extended to 3 seconds or more, whereupon the CNV assumes the appearance of two separate waves (*5, 6*). The earlier wave appears to be related to the nature of the warning stimulus, whereas the second wave depends on motor response requirements and may relate to the readiness potential accompanying uncued movements (*7*).

We now describe an experiment in which CNV's with a foreperiod of 1 second have been synthesized by the simple addition of separately obtained responses to individual sensory stimuli and readiness potentials, none of which depend on any experimental contingency for their appearance. The "CNV's" so synthesized correspond closely to actual CNV's recorded from the same subjects under typical forewarned reaction time (RT) conditions.

Our procedures and results are illustrated in Fig. 1. The data were averaged over eight student subjects (right-handed) and were collected before subjects were given any experimental exposure to the paired-stimuli CNV paradigm. The visual and auditory potentials are based on runs of 40 stimuli each, which were silently counted by the subjects, given at the approximate rate of one per 10 seconds (range, 6 to 14 seconds). The tones were 1000 Hz, 50 msec in duration (including 5-msec rise and fall times), and were delivered through binaural insert earphones at an intensity of 95 dB sound pressure level upon a white noise background of 75 dB. The flashes were 2.3° by 2.3° square (at a viewing distance of 175 cm) and were provided by masking the milk-glass face of a photostimulator (Grass PS2), with the intensity set at 2. The intensity was reduced to 20 percent of its original value by filters in the viewing device, which also provided a dimly glowing fixation cross. The electroencephalogram (EEG) was recorded with silver-silver chloride electrodes and amplified with a time constant of 12 seconds. All trials contaminated with eye movement artifacts (recorded from a pair of electrodes above and below the left eye) were excluded from analysis.

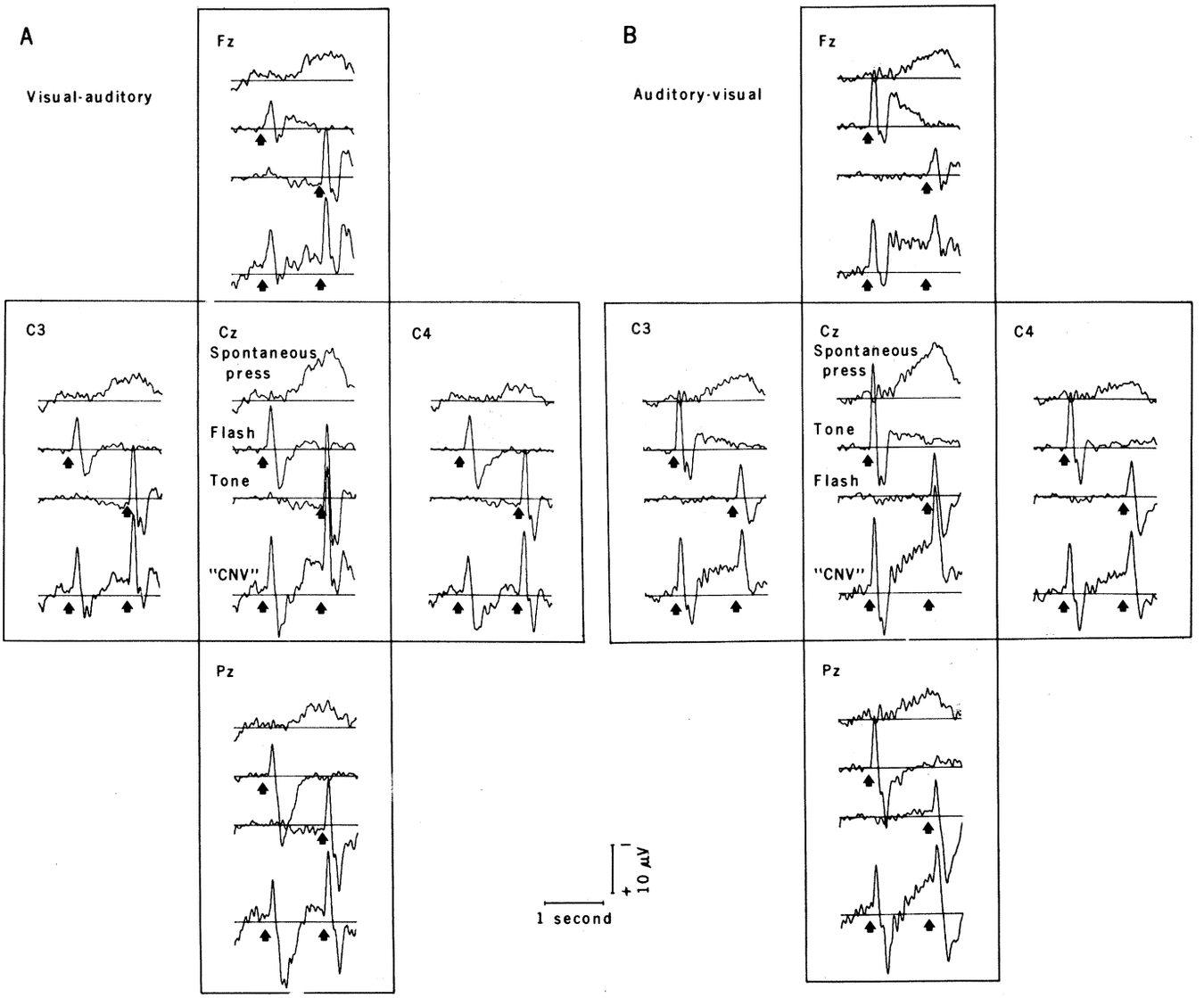

Fig. 1. Potentials from five electrode sites for a visual-auditory (flash-tone) sequence (left) and an auditory-visual (tone-flash) sequence (right). Potentials are shown from electrodes overlying midline frontal (*Fz*), central (*Cz*), and parietal (*Pz*) areas and bilateral left (*C3*) and right (*C4*) motor areas (all referred to linked earlobes). The waveform of the bottom trace in each panel is a synthesized "CNV" associated with the first and second stimuli (arrows), which has been synthesized by simple addition of the upper three waves. The top wave is a readiness potential aligned so that the presses slightly follow the second stimulus (by latencies equivalent to actual reaction times). The second and third waves are potentials elicited by single (unpaired) tone or flash stimuli, with an asynchrony (simulated foreperiod) between the plotted waveforms of 1 second. In addition to the readiness potential, a second major contribution to the synthesized "CNV" is the prolonged negative afterwave that follows the first stimulus at frontal and central sites. Baselines are fitted through the average voltage during the first 500 msec of each trace.

The top trace in each panel is a readiness potential, recorded while subjects made 100 self-initiated key presses (requiring a force equivalent to 750 g through an excursion of 5 mm for complete closure) with the right index finger at an approximate rate of one press per 6 seconds. The averages are synchronized to the response and aligned with the second stimulus, except that a small amount of time jitter and delay were deliberately introduced to copy the variability and latency associated with actual RT responses. The delay and jitter values were obtained simply by drawing on selected trials in a RT distribution collected from the same subjects under actual forewarned RT conditions (*8*).

Several typical features of these individual waves are highlighted in Fig. 1. As often is the case (*9*), the readiness potential is largest at the central (Cz) site and laterally shows a slight preponderance over the hemisphere (C3) contralateral to the hand making the key press. The responses elicited by the first stimulus include a prolonged negative afterwave, which, as we have described (*10*), is largest at the frontal (Fz) site and larger after the tone than after the flash. These individual features are preserved in the composite waveforms shown at the bottom of each panel, wherein the individual waveforms at each electrode site have been added to form synthesized "CNV's" having characteristics typical of actual CNV's.

When acquiring these separate potentials, we have attempted to mimic the psychological conditions surrounding an actual CNV paradigm. (i) We introduced the simple stimulus-counting task during the recording of the potentials elicited by the sensory stimuli. This task would seem to capture the essential character of a CNV warning stimulus, in that subjects are required only to acknowledge the occurrence of a stimulus without having to make any judgment or overt response or to commit it to memory. (ii) We based the readiness potential averages only on those key presses that bore a close temporal resemblance to key presses made under actual CNV conditions. When subjects were making key presses, the associated electromyogram (EMG) (from electrodes overlying the finger flexor muscles in the right forearm) and the throw-time elapsing between the first key displacement and subsequent complete closure were concurrently measured. We have observed generally that subjects, in the absence of specific instructions, are much more sluggish about spontaneous key pressing than they are about RT key presses, pressing with less force, speed, and EMG activity. As a consequence, subjects were encouraged to make their presses briskly in all conditions. Also, when making comparisons among synthesized and actual CNV's, we incorporated into the respective averages only those 15 spontaneous press trials and 15 CNV trials for each subject and condition that were most closely matched on the basis of the associated key throw-time (*11*).

The resultant synthesized "CNV's" are compared with actual CNV's, collected later in the session, in Fig. 2. The subject responded to the second stimulus by pressing a key with the right index finger. The 15 trials in each actual CNV waveform were derived from runs of 40 paired stimuli given at average intertrial intervals of 6.5 seconds (range, 4.5 to 8.5 seconds). The occasional inevitable discrepancies between actual and synthesized waveforms were small in comparison to the overriding similarities during the foreperiod. The critical features are present for both actual and synthesized CNV's: a tendency to be largest at Cz (*3*), the lateral predominance on the side opposite to the hand of response (*3, 12*), the tendency for CNV's with a visual warning stimulus to be relatively later and smaller in their growth than for an auditory warning stimulus (*3, 13*), and, to a lesser extent, the early rise and plateau at Fz (*2-4, 14*).

The essential similarities among synthesized and actual CNV's were confirmed by principal components analysis (PCA). A PCA of the covariance matrix, including both actual and synthesized CNV's, disclosed only two factors related to the slow negative activity during the foreperiod. One factor was apparently associated with the negative afterwave following S1, and the second, with the readiness potential (*15*). Although analyses of variance of the associated factor scores showed significant variation as a function of electrode site and stimulus pairing order, no significant differences were found for the two foreperiod factors that permitted discrimination between actual and synthesized CNV's ($P > .05$ in all cases) (*16*).

The results of this demonstration pertain most clearly to the classical CNV paradigm having invariant warning and imperative stimuli and a nondiscriminative motor response. The extent to which the additive model implicit here may be generalized beyond the simple RT task to situations involving preparation for discriminative responses of varying complexity or acuity remains to be tested. In sum, we believe that the negative afterwave and readiness potential in

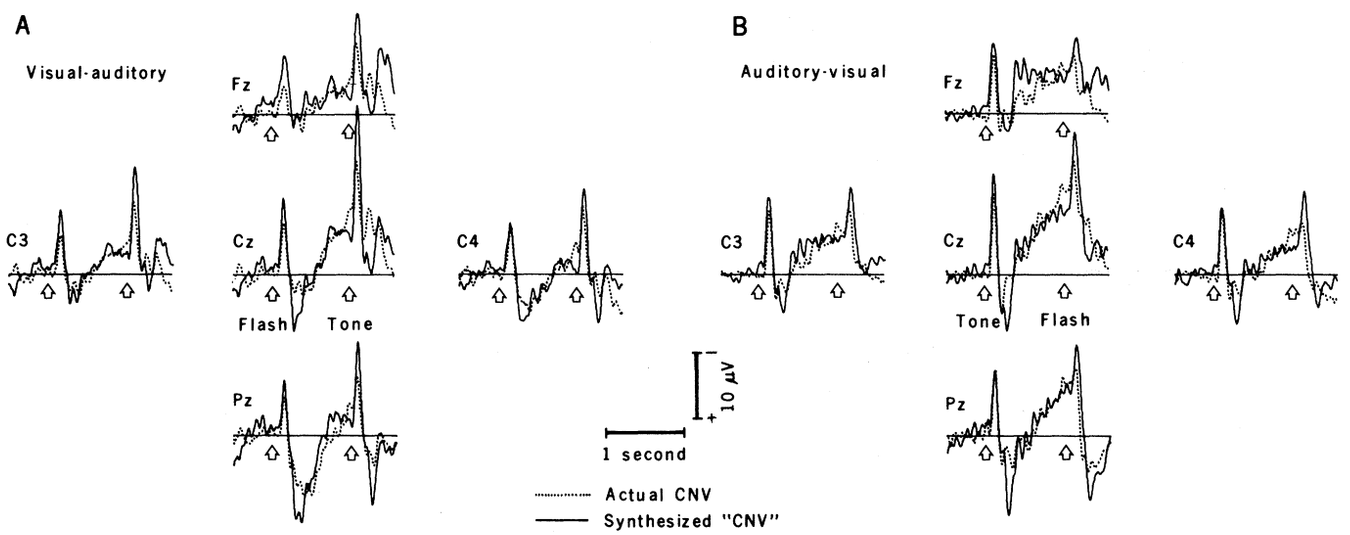

Fig. 2. Comparison of synthesized "CNV's" with actual CNV's.

combination can account for a major portion of the standard CNV waveform. Both of these waves can be recorded individually and do not depend on paired stimuli for their appearance. The primary effects from the pairing of warning and imperative stimuli in a CNV paradigm lie, rather, in the consequent placement of these two waves in temporal juxtaposition or overlap.

Each of the two constituent waves described here can be observed separately with non-CNV procedures. By capitalizing on their distinctive topographical, temporal, and task-related features, it may be possible to design experiments that use these earmarks to make the waves individually accessible with CNV procedures as well. Certainly these individual waves, by themselves, are of interest. One wave, the negative afterwave, may provide an EEG measure of orienting or activation processes (*6, 10*). The second seems to be a movement-related potential; if so, the central determinants of motor outflow (as manifested in these potentials) may become available for scrutiny in demanding task situations, requiring movements that are made to be timed or coordinated with external events. The behaviors related to these separate waves in the CNV are, then, of considerable laboratory and clinical importance, and their assessment separately may permit the establishment of firmer relationships with psychological and motor processes than are now available.

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15. See E. Donchin and E. Heffley [in *Multidisciplinary Perspectives in Event-Related Brain Potential Research*, D. A. Otto, Ed. (Government Printing Office, Washington, D.C., 1978), pp. 555–572] for a discussion of PCA techniques. Each PCA factor represents a separate source of variance identified within the set of waveforms. All factors having an eigenvalue > 1.0 were retained and rotated using the varimax criterion, yielding 15 orthogonal factors. The readiness potential factor (factor 1) accounted for 40.6 percent of the variance, and the afterwave factor (factor 3) accounted for 9.4 percent. The factor structure was similar to that found by McCarthy and Donchin (*4*) for CNV's with a 1-second foreperiod.
16. Repeated measures analyses of variance of the separate PCA factors included as variables the CNV type (actual or synthesized), the pairing order (visual-auditory or auditory-visual), and electrode site. For the readiness potential factor, significant effects ($P < .05$) were found for the electrode site. For the negative afterwave factor, effects were found for pairing order and electrode site; the value for their interaction was .051.
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Feeding Increases Dopamine Metabolism in the Rat Brain

Abstract. *Feeding induced by food deprivation is accompanied by an increased production of the dopamine metabolite 3,4-dihydroxyphenylacetic acid in the brains of rats. This neurochemical change occurs in the nucleus accumbens, the posterior hypothalamus, and the amygdala but not in other dopaminergic nerve terminal fields such as the corpus striatum. These results indicate that the release of dopamine from particular groups of central neurons is increased during feeding and suggest that anatomically distinct subgroups of central dopaminergic neurons serve different roles in the regulation of food intake.*

Central dopaminergic neurons have been implicated in the control of food intake (*1*). Brain lesions which destroy nigrostriatal dopaminergic neurons reduce and sometimes eliminate feeding in rats (*2*). In addition, drugs such as amphetamine inhibit food intake in part by increasing the efflux of dopamine (DA) from central neurons (*3*). Although experimental alteration of central dopaminergic neurotransmission can impair feeding, such findings do not establish that these neurons normally participate in the regulation of ingestive behavior. If central dopaminergic neurons play an active role in the regulation of food intake, then changes in the functional activity of these neurons should accompany hunger, food consumption, or satiety. In order to test this hypothesis, we have monitored the neurochemical changes that normally accompany nerve impulse activity in central dopaminergic projections during food deprivation and during feeding induced by food deprivation. We now report that select populations of nonstriatal dopaminergic neurons are activated during food consumption in the rat.

Measurement of the relative rate of DA metabolism within the brain has been used to estimate the effects of drug, environmental, or behavioral influences on central dopaminergic neurotransmission (*4*). Earlier investigators who have examined DA metabolism in relation to feeding have typically focused on the hypothalamus and have reported conflicting results. Although some investigators have reported that DA metabolism within the hypothalamus is accelerated during food deprivation (*5*) or during feeding (*6*), others have failed to detect such changes (*7*). In the present studies, we have examined DA metabolism in a number of different brain regions innervated by dopaminergic projections (*8*). We have measured the accumulation of the DA metabolite 3,4-dihydroxyphenylacetic acid (DOPAC) in the brain relative to the endogenous concentrations of DA as an index of the relative rate of neuro-

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