Identification of temporal coherence between auditory and visual channels

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The accuracy of identification of the temporal coherence between auditory and visual channels was examined. Random sequences of sound and light bursts were delivered to the left and right sides of an auditory display and of a visual display. The relation of bursts was either coherent between channels (left sound—left light; right sound—right light) or was randomly related. Performance improves as the rate of presentation is decreased, the 75 percent correct threshold level being achieved with about 10 signals/sec. Since excellent coherence discrimination between two auditory variables, or between two visual variables, can be achieved at substantially higher presentation rates, it is presumed that high-speed within-channel processing modes are not available for between-channel processing. The role of sequence predictability within each of the sequences was found to be closely related to the rate of nonswitching within each channel. The limiting factor for between-channel coherence detection appears to be the within-channel nonswitching duration.

It is convenient to discriminate between several broad modes of processing sequential information. When individual items can be separately identified and are presented at a slow rate, perhaps 1-2 items/sec or slower, the items can be processed in terms of their equivalent code. A sequence of low and high tones, for example, can be identified as "high, high, low..." and can be processed in the same manner as any other sequence which can be similarly verbalized. This form of processing has variously been called "cognitive," "intellectual," or "verbal," depending upon the materials employed. The same items can be presented at a more rapid rate, perhaps at 4 items/sec, where an auditory pattern is often "heard" before the constituent elements can be identified (Garner & Gottwald, 1968). Rules for pattern goodness have been developed for such patterns (Royer & Garner, 1970). Finally, we may encode finite-state sequences within the temporal microstructure of auditory and visual signals where extremely large amounts of binary-encoded information can be presented in a short time. Julesz (1962) has examined the depth of visual information processing through the presentation of 105 x 105 matrices within a short flash. Pollack (1971) has examined the depth of auditory information processing with pulse sequences at nearly 10⁴ samples/sec. This form of processing may be called "perceptualization," in that abstract perceptual properties are extracted from the display, e.g., the perceived "texture" or "shape" of a visual display or the perceived "roughness" of an auditory display. The display elements are rarely identified individually. Indeed, one feature of the perceptualization approach is that qualitative features may emerge from the microstructure of the display primarily in the absence of identification of individual display elements.

Informational constraints imposed upon the combination of two auditory variables or upon the combination of two visual variables can also be discerned at extremely fast rates. For example, correlational scatterplots made by combining either independent or common noise voltages (Licklider & Dzendolet, 1948) may be sensed by the ears (Pollack & Trittipoe, 1959) or by the eyes (Pollack, 1960), either for continuous waveforms or for displays discretely sampled at high rates of presentation.

Since the eye can discern correlations with respect to two visual dimensions and since the ear can discern correlations with respect to two auditory dimensions, at extremely high presentations rates, each modality is assumed to operate within the "perceptualization" mode of processing. Can this mode be attained with correlations between one auditory and one visual dimension?

An answer to the preceding question will be sought in terms of the temporal limits upon between-modality correlation identification and in terms of the sensitivity to manipulations of the temporal microstructure of the signals. A preliminary test, which made no attempt to explore optimal conditions for between-modality detection, was unsuccessful in achieving high rates of presentation for combinations of auditory, visual, and vibrotactile stimuli (Pollack, 1974). The present tests explore a wider range of conditions in order to seek optimal conditions for auditory-visual correlation detection.

METHOD

Approach

The subject was presented with a train of auditory bursts, successively delivered in a random temporal sequence to the left and right earphones, and with a train of visual bursts, successively delivered in a random temporal sequence to the left and right sides

of the visual display. His (her) task was to determine whether the sound and light sequences were coherently related (left earphone paired with the left side of the display; right earphone paired with the right side of the display) or whether the sound and light sequences were randomly related (left and right earphones paired equally often with each of the two sides of the display).

The top half of Figure 1 defines two extreme correlations between auditory and visual sequences. A *coherent* temporal relation defines a perfect correlation: the left earphone (L auditory) is activated along with the left side of the visual display (L visual); the right earphone is activated along with the right side of the visual display. Burst by burst, in time, the two displays are locked in step. A *random* temporal relation defines a zero correlation: each of the two earphones is equally likely to be activated along with each of the two sides of the display. Burst by burst, in time, the two displays are randomly related. Intermediate conditions between the extremes were obtained in the following manner. A random sequence of auditory states, L or R, was generated without constraint. The visual sequence was generated in conjunction with a controlled probability of agreement between the channels, PAG. A coherent relation is represented by $PAG = 1.0$; a random relation is represented by $PAG = 0.50$; a reverse relation is represented by $PAG = 0$; and intermediate conditions are represented by intermediate PAG levels.

Many possibilities exist in arbitrarily choosing auditory and visual displays, e.g., amplitude, frequency, or wave length, or direction, as employed here. Left vs. right direction was employed because all senses—including the slower acting chemical senses—demonstrate fine temporal discrimination across the body midline (Békésy, 1964a, b), and because within-modality comparisons were available for the two ears or for left-right, up-down directions.

Procedure

A trial consisted of 25 successive observations. Each observation consisted of a pair of sequences—one auditory and one visual. The sequences were related at one of two PAG levels, typically $PAG = 0.50$ and $PAG = 1.0$, with all other parameters fixed. The order of the two PAG levels was randomly scrambled. Each paired sequence was initiated by the subject. After presentation of a pair of sequences, (s)he pressed one of two buttons to identify whether the relation between the channels was random or coherent. Selective attending, either to the visual channel alone or to the auditory channel alone, did not provide information to the subject. Each sequence, when viewed alone, is a random sequence, irrespective of PAG level. The subject was immediately informed of the correctness of his response. The number of responses correct out of 25 observations defined the performance level.

Experimental Details

An earphone or a light display may be activated by a single pulse of sufficient intensity. Instead, the "left" state was here defined by a *burst* of pulses, 10 μ sec in duration, delivered to the left earphone or to the left side of the display. The "right" state was here defined by a burst of pulses delivered to the right earphone or to the right side of the display. The lower half of Figure 1 illustrates the time structure within two successive bursts: there were P pulses per burst; each pulse was separated by an interpulse interval, ipi ; successive bursts were separated by an off interval; and the onset-onset interval between successive bursts is termed the interburst interval, or IBI . A sequence consisted of B successive bursts. Unless specified otherwise, $B = 24$, $ipi = 0.18$ msec, the off interval was 0.3 msec, and the sequence of sounds alone or of lights alone was each random. It is important to note that an ipi of 0.18 msec indicates that pulses were delivered within a burst to the earphone or to the display at 5,500 pulses/sec, *without* change of state within a burst. The ipi primarily defined the auditory quality of each burst. By contrast, the interburst interval defines the rate at which the display can change in terms of left and right states. The informational rate of the display, therefore, is linked with the

AUDITORY-VISUAL COHERENCE & TIME STRUCTURE

Figure 1. Illustration of temporal coherence between sequences of auditory and visual bursts (top half) and of temporal microstructure of two bursts (bottom half).

interburst interval, and not with the interpulse interval. Temporal coherence is defined with respect to the left and right states of successive bursts, not with respect to individual pulses within a burst.

Subjects were university students experienced in psychophysical testing. Earphones were Grason-Stadler TD-39; the display was a Tektronix 602 equipped with a fast P15 phosphor. Individual auditory pulses were about 50 dB above threshold. An 8 x 8 cm area was available for plotting. The subject sat 70 cm from the visual display. Each point represents 25 blocks of observations contributed by 13 observers. Over 624 experimental conditions, 0.39×10^6 observations are represented. Testing was performed individually. The experiment was controlled by a PDP-8 computer.

Constrained Sequences

In special tests, sequences of 20 bursts each were internally constrained in terms of the conditional repetition probability, CRP, within the sequence. With CRP = 0.8, for example, the probability of successively repeating a flash on the same side as that of the previously presented flash was 0.8. Coherence relations were of two types: in each case, the auditory sequence was generated with respect to CRP; and the visual sequence was either perfectly correlated with the auditory sequence or independently generated at the same CRP. Selective attending to either sequence alone again does not provide differential information with respect to the temporal coherence between the channels.

RESULTS

(A) Coherence Identification over the Entire Sequence

Intermediate coherence levels. Sequences at intermediate coherence levels were intermixed with sequences with a random coherence level ($PAG = 0.50$) and presented for identification. A sequence of 24 bursts at an interburst interval of 258 msec—or less than 4 bursts/sec—was employed. The percentage of correct responses, $P(C)$, is listed in Table 1 as a function of the intermediate PAG level. Performance improves as the PAG level is displaced from 0.50, either above or below 0.50. Near-linear functions are obtained for each half of the table when PAG and $P(C)$ are each expressed in normal deviate form. It is noted that 75% correct performance is achieved for PAG levels of .10 and .90 when the sequence of left and right bursts was less than 4

Table 1
A-V Coherence Identification of Random vs. Partial Coherence

PAG	P(C)	PAG	P(C)
.001	89	.999	97
		.95	81
.10	75	.90	73
.15	64	.85	69
.20	52	.80	66
.25	57	.75	64
.30	53	.70	61
.35	50	.65	54
.40	49	.60	50

Note—PAG = probability of agreement between auditory and visual channels, P(C) = percentage correct identifications.

Table 2
A-V Coherence Identification and Range of Relevant x and Irrelevant y Variation

Range of y Variation (cm)	Range of x Variation (cm)				Average
	0	1	2	4	
RS*	81	85	79	68	78.2
0	86	82	84	70	80.6
1	85	80	84	70	79.7
2	86	82	82	72	80.2
4	83	85	81	69	79.3
8	82	81	78	63	75.9
Average	83.7	82.4	81.2	68.7	

*RS = regularly spaced on y variation.

bursts/sec—a far cry from thousands of items per second possible with within-modality correlation detection. In order to determine limits on temporal parameters, later tests will contrast a random coherence from a perfect coherence (PAG = 0.5 vs. PAG = 1.0).

Range of variation in the visual channel. In order to achieve high visual flash rates without fusion, the location of successive visual bursts was jittered within fixed bounds. (All of the pulses within a single burst formed a single dot.) The range of the relevant x dimension varied from 0 cm (in which the two visual states were represented upon the display by single points at $x = 0$ cm and at $x = 8$ cm) to 4 cm (in which the left visual state was represented by a uniform distribution of x between 0 and 4 cm, and the right visual state was represented by a uniform distribution from 4 to 8 cm). The range of variation of the y coordinate varied from 0 to 8 cm. The condition RS represents a regular spacing in which successive y values were marched down in 1-cm steps. Results are averaged over IBIs of 160, 225, and 318 msec for trains of 6 bursts.

The main finding, shown in Table 2, is that there is little effect upon performance of x and y variation, except for extremely large variations in the relevant x dimension.

Since small degrees of jitter did not seriously affect performance at the relatively slow interburst intervals

examined, the balance of tests over a wider range of conditions employed an x and y variation of 1 x 1 cm in the upper left and right corners of the visual display.

Role of IPI and IBI. Figure 2 shows the role upon coherence identification of variation in the interpulse interval, ipi, and of variation in the interburst interval, IBI. Sequences of 6 visual bursts and 6 auditory bursts were employed with an off time of 0.3 msec between successive bursts.

The main result is that performance is strongly determined by the interburst interval, IBI. Near-chance performance is obtained at an IBI of 50 msec, or 20 bursts/sec; near-maximum performance is achieved at an IBI of 1,000 msec, or 1 burst/sec. Although one ipi level yields a small, but consistent, advantage over the other interpulse intervals, the main thrust is that the accuracy of coherence detection is overwhelmingly determined by the rate of presentation of the states within the auditory and visual sequences, and not with the detailed temporal microstructure within each burst. Additional tests jointly varied ipi and the off interval between bursts. Again, the IBI was the overwhelming determinant of performance.

Effect of number of bursts, B, and the interburst interval, IBI. The number of bursts within a sequence labels the columns of Table 3, and the interburst interval labels the rows of Table 3. An interpulse interval of 0.18 msec was employed. The results for 6 bursts at ipi = 0.18 msec are replicated from Figure 2.

For a fixed number of bursts, sighting down each column, performance improves with the interburst

Figure 2. Accuracy of coherence identification as a function of the interval between successive bursts (abscissa) and of the interval between successive pulses within a burst (parameter).

Table 3
A-V Coherence Identification, Interburst Interval
(Milliseconds), and Number of Bursts

IBI	Number of Bursts (B)									
	3	6	12	24	48	96	192	384	768	
12								52		
16							59	55		
23						58	56	56		
32					52	58	63			
46				56	68	67	72			
65			64	68	74	81				
91	62	59	60	73	82	86				
129	65	75	79	81	88					
183	64	80	84	93	93					
258	64	90	93	97						
364	84	93	95	97						
516	84	93	95							
721	87	92								

interval; for a fixed interburst interval, sighting across each row, performance improves with the number of bursts.

Since performance improves both with B and with IBI, performance also improves with the duration of the sequence, represented by the product of B and IBI. The straight line represents one such product. Proportional changes in IBI are more effective than proportional changes in the number of bursts. The general statement is subject to several limitations: extremely short or extremely long interburst intervals are not extremely effective, and there is large improvement from a sequence of 3 to 6 bursts. The latter improvement is due to a limitation imposed upon maximum performance at small B, irrespective of IBI. With $B = 3$, in one of eight observations, the 3 light bursts will be coherent with the 3 sound bursts, when $PAG = 0.50$ is employed. Assume the following decision rule is used: say "coherent" when all bursts are coherent; say "random" when at least 1 burst is in disagreement. A P(C) score of 100% can be obtained on observations when $PAG = 1.0$, and a P(C) score of 87.5% can be obtained on observations when $PAG = 0.50$ with $B = 3$. Since both observations occur equally often, an average P(C) score of 93.8% can be obtained with $B = 3$. And, in general, the maximum score is $1.0 - 2/(B+1)$, or a score of 99.2%, with $B = 6$.

Why are there further gains in performance with still longer sequences of bursts beyond 6? Tentatively, it is assumed that longer sequences provide the opportunity for longer runs of bursts within the same state, and, in a manner not well specified, the subject notes the simultaneous occurrence of the nonchange in state represented by the longer runs. Presumably, procedures which slow down the rate of switching within channels but do not alter the rate of presentation of successive bursts also improve coherence identification. This presumption will be tested later.

(B) Coherence Identification over Selected Portions of the Sequence

First burst and last burst alone. If the subject could have perfectly identified the coherence of only the first burst alone, or of only the last burst alone, in the previous tests, (s)he could have achieved a score of up to 75% correct. Had (s)he been able to identify the agreement of both the first and of the last bursts, (s)he could have achieved a score of 87.5% correct. Since these scores were not achieved in many conditions, and since the accuracy of identification was related to the total number of bursts in the sequence, we might conclude that subjects did not, and perhaps could not, identify the agreement of the first and last bursts alone.

Different subjects, however, adopt different strategies. In order to determine the accuracy of identification of individual bursts, separate tests were run over a range of signal rates with trains of 2-65 bursts. The task of the observer was, in one test, to identify the agreement of the first burst alone, and, in another test, to identify the agreement of the last burst alone. The subject was informed about the coherence relation between the intermediate bursts so that (s)he could concentrate upon the selected burst. Averaged over a wide range of interburst intervals, the identification scores are shown in Table 4.

In one-half of the sequences, the first or last burst was in agreement between the two channels, and the correct response was "in agreement"; in half of the sequences, the first or last burst was in disagreement between the two channels, and the correct response was "not in agreement." Tests were run with the other, noncritical bursts of the sequence coherently related ($PAG = 1.0$) or randomly related ($PAG = 0.50$). There was little difference, on the average, in the accuracy of identifying the agreement of the first and the last bursts alone, with an average score of 73% correct. There was somewhat higher accuracy when the critical bursts were in agreement, especially when the other bursts were also coherent.

Another demonstration that the accuracy of identifying the coherence of the first burst alone, or of the last burst alone, is sensitive to the remaining context is shown by the effect of interburst interval.

Table 4
A-V Coherence Identification for First Burst
Alone and for Last Burst Alone

PAG (Other)	Critical Relation in Disagreement		in Agreement		Average
	.50	1.0	.50	1.0	
First Burst	69	67	74	81	72.7
Last Burst	70	70	70	82	73.2

Table 5
A-V Coherence Identification for the First or Last Burst Alone

	Interburst Interval (IBI) in Msec								
B-1	49	69	98	139	196	277	392	533	782
0	94		94		93		96	96	93
1	65	63	70	81	85	90	88	89	91
2	55	60	62	77	82	92	88	91	91
4	55	56	62	75	77	94	87	91	93
8	54	58	59	69	81	86	87		
16	54	57	63	72	79				
32	53	58	61						
64	53								
Average									
1-4	58	60	64	78	81	92	88	90	92

The columns of Table 5 are headed by the interburst interval, the rows by the number of bursts in the remainder of the sequence. The entries represent the proportion of correct identifications, averaged over judgments of first burst alone and of last burst alone. The off time was constant at 0.3 msec. The duration of the burst was equal to IBI minus the constant off time, even without the context of another burst ($B - 1 = 0$).

The accuracy of identifying the coherence of the first burst alone, or of the last burst alone, improves as IBI is increased, at least to 277 msec. At all interburst intervals, there is an advantage of 0 and 1 "other" bursts, with little additional change beyond 2 "other" bursts, thereby implying a highly local context effect.

Intermediate segments. Two further series of tests explored the effect of context on coherence identification of restricted segments of the entire sequence. Over the entire sequence of B bursts, an intermediate segment of B_2 bursts was flanked by segments of B_1 and B_3 bursts. Except for the coherence relation between channels, the separate segments were not marked for the subject. The subject was fully informed with respect to the coherence relations of the segments.

In one series, the coherence of the flanking B_1 and B_3 bursts was chance and that of the intermediate B_2 bursts was either chance or perfect. The task was to detect an intermediate coherent relation amidst an otherwise random relation between the auditory and visual sequences.

The first column of Table 6 lists the number of bursts in the middle section, B_2 ; the second column lists the number of bursts in each of the flanking sections, B_1 and B_3 . The columns are headed by IBI. Performance falls as the number of bursts of the flanking sections increases above 0 or 1, again showing a local context effect. Performance also improves with the number of intermediate bursts and with IBI. These results would be expected if the duration of the intermediate section were important relative to that of the flanking bursts.

In another set of tests, the coherence of the flanking B_1 and B_3 bursts was perfect and the coherence of the intermediate B_2 bursts was either perfect or reverse, i.e., always on the opposite side. The task was to detect a deviation from a perfectly coherent relation. Results are shown in the top half of Table 7 for sequences with only a single intermediate B_2 burst. Performance improves as the interburst interval is increased, but is relatively independent of the number of flanking bursts beyond the case of zero flanking bursts. Results with more than one intermediate B_2 burst are shown in the lower half of Table 7. The

Table 6
A-V Coherence Identification of a Middle Section With Random Flanks

		Interburst Interval (IBI) in Msec						
B_2	$B_{1,3}$	69	98	139	196	277	391	553
4	0				80	89	85	82
	1				56	61	69	71
	2				60	61	63	64
	4				56	57	62	66
	8				54	52		
8	0		64	81	82	89	77	
	1		60	73	72	73	74	
	2		57	67	67	71	70	
	4		57	67	60	70	67	
	8		57	56	63	65		
16	16		53	54				
	0	66	72	85	78	84		
	1	61	70	80	79	85		
	2	63	68	76	79	81		
	4	60	61	71	77	80		
	8	61	56	66	69			
	16	52	59	67				

Table 7
A-V Coherence Identification of Middle Section With Coherent Flanks

		Interburst Interval (IBI) in Msec				
$B_2 = 1$		26	52	105	209	418
B_1, B_3	0	91		91		93
	1	56	61	80	89	91
	2	55	66	82	90	88
	4	56	61	78	80	
	8	53	59	73		
	16	54	56			
	32	54				
	64	55				
	B_2 Varied	26	52	105	209	418
		32	16	8	4	2
B_2	1	54	56	73	80	88
	2	57	62	76	84	90
	4	56	62	84	89	
	8	59	64	82		
	16	57	74			
	32	58				

number of B_2 bursts is shown in the first column. The succeeding columns are headed by the interburst interval and the number of flanking B_1 and B_3 bursts. The product of the number of flanking bursts and IBI equaled approximately 830 msec. In this task, performance is relatively insensitive to the number of intermediate B_2 bursts. The previous generalization that the identification of random vs. perfect coherence is relatively constant for a constant duration of the critical region does not appear to hold up for the detection of reversals from perfect coherence. In the latter case, the subject may have been noting the frequency of shifting of location, rather than coherence of locations, as such, since the temporal pattern of shifting is identical within the perfect reversals as within perfect coherences.

In partial summary, it is unlikely that the accuracy of coherence identification in the main tests (Section A) was determined primarily by the identification of coherence of single bursts with the sequences.

(C) Attempts to Enhance Coherence Identification

Left-right vs. burst-no burst. One reasonable hypothesis is that coherence identification is related to the rate of switching between the two auditory states and between the two visual states. Might substantially better performance be obtained if the binary states of the light and sound channels were marked by the absence or presence of the sound and of the light rather than by the presentation of two different states within each modality? From the experimenter's point of view, such tests are identical to the previous tests, except that signals to the right side of the display and signals to the right earphone were "disconnected." From the subject's point of view, the two forms of presentation are identical if one of the two states of each channel were functionally "blocked out."

Thirty-five conditions, representing a wide range of variables, were run with the two states of each variable represented either by two locations or by the absence or presence at a single location. Over the entire range of conditions (interpulse intervals from .18 to 22 msec, interburst intervals from 46 to 260 msec), there was only a slight advantage in favor of absence-presence (20 cases higher, 14 cases lower, 1 tie). Over a restricted range of interburst intervals from 55 to 63 msec, however, there was a strong advantage in favor of absence-presence (10 cases of 11), with an average difference of 6.8% correct. Otherwise, performance improved at longer interburst intervals, irrespective of the variation in the on-off structure of the signals, as previously noted.

Effect of number of pulses and time delay. One possible reason for poor coherence detection at short interburst intervals is that the times for processing the auditory and visual information are not identical, so that the two sequences may be out of phase at some

central locus for comparison. Might a consistent imbalance or delay introduced into either channel improve discrimination? A wide variety of leads and lags were introduced in units of the number of pulses and of the interpulse interval, ranging from 2 to 512 pulses, burst.

With a constant number of pulses, 256 or 512, in each burst within one channel, there was no advantage of a visual lead or of a visual lag. There was an appreciable loss in performance only when a small number of pulses was delivered to the visual channel, which presumably was related to a lowered dot brightness. Otherwise, there were no systematic effects of the number of pulses delivered within each burst to each channel. If we assume that the rate of channel switching is the limiting factor in between-channel coherence detection, the introduction of a consistent lead or lag would have little effect, except possibly if there were strong asymmetries in switching between channels. Most studies on the perception of temporal order have considered the discrimination of the onset or the offset of a single burst within each channel (e.g., Kristofferson, 1963). An elegant description of classes of theories related to central switching is available in Sternberg and Knoll (1973).

Internal structure of sequences. Motion-picture engineers have long demanded tight specification upon the delay between the sound and picture tracks of a motion picture. Since we can easily detect unsynchronized motion-picture sequences, this result suggests that, in the present task environment, we might improve coherence detection substantially if we employed sequences with internal statistical constraints. An average rate of speaking is about 150 words/min, or about 3.7 syllables/sec, which is in the ballpark of the burst presentation rates employed here. Incidentally, the apparent location of a sound at its visual origin, the "ventriloquism effect," has been shown to be greater with appropriate stimuli (auditory tones with pictures of push-button responses or heard speech with pictures of mouth movements) than with inappropriate stimuli (auditory tones with mouth movements or heard speech with pictures of push-button responses) (Jack & Thurlow, 1973; Thurlow & Jack, 1973).

Sequences of 20 auditory and visual bursts were generated at the same within-channel conditional repetition probability, CRP, ranging from 0.50 (as in the earlier tests) to 0.999. In half of the observations, the auditory and visual bursts were perfectly correlated. In half of the observations, the auditory and visual bursts were independently generated with the same CRP.

The results are shown in Table 8. The first column is the CRP; the second column is the equivalent average run length, ARL, which is equal to $(1 - \text{CRP})^{-1}$. The other columns are headed by the

Table 8
A-V Coherence Identification, Interval Structure,
and Interburst Interval

CRP	ARL	Interburst Interval in Msec				
		41	58	82	115	230
.50	2	53	61	60	76	90
.60	2.5		64	67	81	92
.70	3.33	65	65	78	83	88
.75	4		70	72	82	84
.80	5	64	68	76	82	89
.85	6.67	67	77	80	78	85
.90	10	70	78	82	86	88
.95	20	77	79	82	81	84
.999	1000		60	66	64	67

interburst interval. The entries represent the proportion of correct observations, based upon 32 blocks of 25 observations. Performance tends to improve as the CRP is increased, except for a sharp drop with a CRP approaching unity. (The sharp drop at CRP of .999 is due to the fact that on one-quarter of the observations, noncoherent sequences were actually in perfect agreement. Since the entire sequence was determined by the initial state alone, the maximum possible performance that could have been achieved in this case was 75% correct.)

Since performance improves with CRP and since the predictability of the sequences is related to CRP, the results of Table 8 appear to support the proposition that performance is related to the predictability of the sequences. This proposition can be further tested. Binary sequences with a CRP of $(.50 + X)$ are, in a formal statistical sense, equally predictable to those with a CRP of $(.50 - X)$. Therefore, if predictability were the crucial factor, we should anticipate the same effects upon performance of varying CRP, both below and above 0.50.

Table 9, however, shows that for an interburst interval of 82 msec, performance is not symmetric about a CRP of 0.50. Instead, performance grows monotonically with CRP. The critical variable, then, cannot be the predictability of the sequence. Performance appears to be closely related to the average run length, ARL, shown in the last column of Table 9.

Table 9
A-V Coherence Identification for Internally
Constrained Sequences

CRP	P(C)	ARL	CRP	P(C)	ARL
.001	52	1.00	.999	.66	1000
.05	54	1.05	.95	.82	20.0
.10	56	1.11	.90	.82	10.0
.15	57	1.17	.85	.80	6.67
.20	57	1.25	.80	.76	5.00
.25	57	1.33	.75	.72	4.00
.30	57	1.43	.70	.68	3.33
.40	61	1.67	.60	.67	2.50
.50	60	2.00			

For sequences with a fixed number of bursts, the average run length is, in turn, related to the longest run length and/or to the run length of longest duration. From this point of view, the critical feature may be the longest duration of the sequence before within-channel switching. A weak test of this proposition is the following: assume that the longest run length is proportional to ARL; the longest duration without switching within channels is then proportional to the product of ARL by the interburst interval, IBI. For equal products of ARL and IBI, we might predict equivalent performance. The result is approached in Table 8 for one such product, approximately 575 msec as indicated by the broken line, but is not fully attained at the shortest interburst intervals.

DISCUSSION

Between-channel temporal coherence identification can be accomplished only at substantially lower rates of information presentation than within-channel temporal coherence identification. Within-channel coherence identification appears to rely on the emergence of perceptual properties (shape in a visual display, roughness or diffuseness in an auditory display) based upon the detailed microstructure of the signals. Such a processing mode is presumably not available in between-channel temporal coherence identification. In addition, manipulations in the temporal structure are relatively ineffective for between-channel presentation.

Between-channel temporal coherence identification appears to be sensitive to the longest duration of nonswitching available within each channel. Operations which increase this duration—increasing the interburst interval, increasing the number of bursts within each channel, or increasing the run probability—all improve between-channel temporal coherence identification. Operations which do not change this duration—change in the pulse repetition rate within bursts, modification of the on-off fraction, introduction of a constant lead or lag—all fail to change performance.

The results suggest that between-channel temporal coherence identification, for binary-coded materials at least, is not accomplished by recognition of the individual occurrences of each state. Rather, in a manner not well specified, the duration of nonswitching within the separate channels appears to be crucial.

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