METHODS & DESIGNS

Tables of event sequences for sequential analyses of data in psychological experiments containing two-class events¹

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Tables of sequences of two-class events are presented for use in programming psychological experiments in which behavior on trial n may be a function of the events of trials $n - 1$, $n - 2$, and/or $n - 3$. Various factors related to schedule generation are discussed, i.e., restrictions on trial-block length which accompany sequential balance, interrelationships of trial blocks in the multiblock experiment, relationships between run length and r -tuple occurrences, and alternation behavior. Following a consideration of various methods of schedule generation for the two-class experiment, it was concluded that no method can result in schedules that possess all properties considered desirable in psychological experiments. However, the present sequences allow for sequential balance and analysis, and thus should prove useful in producing schedules in some contexts that are standard with regard to sequential influences.

The following tables contain computer-generated sequences characterized by equal numbers of two-class events (designated as 1 or 0), which can be utilized in programming psychological experiments involving several presentations of each event when sequential analyses of behavior and counterbalancing of event sequences are desired. Although sequential analyses have already been used to define much about learning processes which could not be observed directly from the customary trial-block summary measures, these tables constitute the first presentation of a variety of schedules for which transitional occurrences (11, 10, 01, 00) are balanced within trial blocks for various numbers of trials preceding the measurement trial.

APPROACHES TO EVENT SEQUENCES

The sequential arrangements of treatments in experiments have long been of concern to psychological investigators. Random methods of event generation, of course, have been utilized in many

experimental contexts to minimize various artifacts related to average placement and pattern discriminability of treatments. However, without restrictions the random approach, by definition, disallows any control of various aspects of sequential occurrences within a finite experimental situation. As will be discussed later, to obtain certain types of control, the nature of restrictions on randomization can become quite complex.

Gellermann (1933) constructed a set of 44 series in an attempt to cope with problems in discrimination learning related to position preferences and tendencies of Ss to alternate responses in experiments containing two response alternatives. Each of the Gellermann series contains 10 events, 5 of each type, with the possibility existing for series to be combined to provide for the programming of an experiment length that is some multiple of 10.

Some investigators (cf. Frey, 1969; Moore, 1964) have utilized schedules composed of an equal number of runs of lengths 1, 2, and 3 for each of two event classes. These schedules have lengths that are some multiple of 12 events, e.g., the sequence 101100111000 has the specified properties. When each sequence serves as one of a series of trial blocks and when a transition from one event class to the other class occurs at each junction between successive blocks, these schedules are characterized by each event class having been preceded equally often by events of both classes.

Various Latin-square designs have been developed to deal with somewhat different concerns about the sequential patterns of treatment presentation (e.g., Bradley, 1958; Cochran & Cox, 1957; Grant, 1948; Patterson, 1952). These designs typically have involved rather short series of events and three or four different types of treatments. Additionally, these designs usually cover situations in which treatments are not repeated for the same individual, or are repeated only once. The basic concerns in their development have been to ensure that each treatment has the same average placement in the sequence and that each treatment has been preceded equally often by every other treatment.

In the development of the present sequences, the experiments of primary concern have been those involving two-class events with several, but equal, repetitions of each event, e.g., experiments in differential conditioning, discrimination learning, partial reinforcement, and probability learning. The goal has been to develop sequences in which the residual effects of trials $n - 1$, $n - 2$, and/or $n - 3$ could be balanced and statistically assessed for individual Ss. Thus, although all of the listed methods are related to each other in some respects, none share identical properties, and each has been developed to deal with different situations or concerns.

PROPERTIES AND GENERATION METHOD OF PRESENT SEQUENCES

Conceptually, each of the present series

TABLE 1

SEQUENCE LENGTH = 4	SUBSEQUENCE LENGTH = 2
TERMINAL EVENT OF PRECEDING SEQUENCE : 1	
1. 0011	2. 1001

TABLE 2

SEQUENCE LENGTH = 8	SUBSEQUENCE LENGTH = 2
TERMINAL EVENT OF PRECEDING SEQUENCE : 1	

1. 10001011	2. 10001101	3. 00010111
4. 10011001	5. 11001001	6. 00110011
7. 11010001	8. 00011011	9. 01000111
10. 01100011	11. 00111001	12. 11000101
13. 01110001	14. 10010011	15. 00100111
16. 10100011	17. 00011101	18. 10110001

TABLE 3

SEQUENCE LENGTH = 8

SUBSEQUENCE LENGTH = 3

TERMINAL EVENTS OF
PRECEDING SEQUENCE : 11TERMINAL EVENTS OF
PRECEDING SEQUENCE : 10

1. 00010111
2. 01000111
3. 10100011
4. 10001011

1. 11100010
2. 00101110
3. 00111010
4. 10001110

TABLE 4

SEQUENCE LENGTH = 12

SUBSEQUENCE LENGTH = 2

TERMINAL EVENT OF PRECEDING SEQUENCE : 1

1. 011000010111	2. 001000110111	3. 000101111001	4. 110101100001
5. 001110001011	6. 000111001101	7. 100100111001	8. 111000010101
9. 100001011101	10. 100110110001	11. 001110011001	12. 100110001101
13. 000111100101	14. 100010111001	15. 000100011011	16. 100111010001
17. 101000100111	18. 000101100111	19. 001100010111	20. 011100011001
21. 100011001101	22. 100011100101	23. 110010010011	24. 000111001011
25. 110010011001	26. 001100110011	27. 111000100101	28. 101000110011
29. 010001001111	30. 000110011011	31. 001001001111	32. 111000101001
33. 100100010111	34. 000110101111	35. 111001000101	36. 010000101111
37. 011000011101	38. 100110001011	39. 000011011011	40. 110001001101
41. 000110110011	42. 100100100111	43. 000010101111	44. 101001100011
45. 000110100111	46. 001100011011	47. 100001101011	48. 110010001101
49. 010011110001	50. 011100001011	51. 001011100011	52. 011100011001
53. 100100110011	54. 100111000101	55. 100100001101	56. 001001110011
57. 000010111011	58. 010001110011	59. 010100001111	60. 110100100011
61. 000010111011	62. 000110011101	63. 101000111001	64. 111010000101
65. 101101100001	66. 010011000111	67. 011000100111	68. 001110001101
69. 010110000111	70. 001111000101	71. 100011010011	72. 000101001111
73. 110110100001	74. 110011010001	75. 101110001001	76. 110110100001
77. 101101000011	78. 100010100111	79. 100010110001	80. 111010100001
81. 110100010011	82. 001111010001	83. 100110010011	84. 011110100001
85. 001111100001	86. 000100110111	87. 011011000011	88. 110110001001
89. 010000111101	90. 011001100011	91. 101100110001	92. 010010001111
93. 100101000111	94. 110100110001	95. 110101000011	96. 000011101011
97. 110000101011	98. 011001100011	99. 110001101001	100. 110001011001
101. 000100111101	102. 011000111001	103. 110011000101	104. 000011101101
105. 110011001001	106. 100001011011	107. 011000011011	108. 010001111001
109. 001100011101	110. 011011000011	111. 011100110001	112. 011110000101
113. 101100001011	114. 000011110101	115. 001101000111	116. 010000110111
117. 110001001011	118. 110010100011	119. 001000101111	120. 111001010001
121. 101000010111	122. 101011100001	123. 000101110101	124. 000100101111
125. 011100010011	126. 110000110101	127. 101000011011	128. 011101000011
129. 100011001011	130. 010001110101	131. 100010011011	132. 100001011111
133. 010111000011	134. 110010110001	135. 000111010001	136. 001001100111
137. 001000110111	138. 011100010011	139. 000110110001	140. 010011100011
141. 101100001001	142. 101010000111	143. 101010000111	144. 010110000111
145. 100010010111	146. 100101100011	147. 001100111001	148. 101110000101
149. 101001110001	150. 111010001001	151. 001101100011	152. 011011100001
153. 110010001011	154. 001111100011	155. 101110100001	156. 110001100101
157. 011100001011	158. 001110010011	159. 001011110001	160. 110110000101
161. 100010011101	162. 100001110101	163. 100001101101	164. 011001110001
165. 001111001001	166. 110100001011	167. 101110010001	168. 101001000111
169. 011110010001	170. 001000101111	171. 100110011001	172. 110100011001
173. 001000111101	174. 011100001011	175. 001011000111	176. 101100100011
177. 000110010111	178. 100010110011	179. 110000101101	180. 101011000011
181. 001100100111	182. 101000011101	183. 001110100011	184. 110001010011
185. 000101110011	186. 000101110011	187. 000111010011	188. 100011101001
189. 010001100111	190. 011001000111	191. 000111010011	192. 010111100001
193. 110100001001	194. 110010010011	195. 001001110001	196. 110100100011
197. 100101110001	198. 100111001001	199. 100100011011	200. 011110001001

has been viewed as one trial block within a longer experiment and, therefore, the series have been grouped according to their appropriateness following given terminal events of a prior sequence. The present sequences, each of which functions as a trial block of length 4, 8, 12, or 16 in an experimental context, are characterized by equal representations of each event and all possible overlapping subsequences of specified length. Hereafter, the term *r*-tuple

will be used as a synonym for overlapping subsequences of length *r*.

If the terminal event of a preceding sequence is counted, the four-event sequences of Table 1 possess each of the possible 2-tuples, e.g., combining the terminal event of the preceding sequence 1, with Series No. 2 leads to the sequence 11001, which contains the 2-tuples 11, 10, 00, and 01. Since each class of event in the block has been preceded once by 1 and

once by 0, behavior can be analyzed as a function of the event immediately preceding the measurement trial.

In Table 2 each of the eight-event sequences contains two each of the possible 2-tuples, if the terminal event of a preceding sequence is counted. The eight-event sequences of Table 3 are a subset of those in Table 2 which contain all possible 3-tuples, i.e., 111, 110, 101, 100, 011, 010, 001, and 000. For these Table 3 sequences, each class of event is preceded equally often by each 2-tuple, so that it is possible to assess the effects of events of trials $n - 1$ and $n - 2$ on behavior occurring at trial n .

Table 4 shows sequences of length 12 having equal representation of all length-2 subsequences, and Tables 5 and 6 list 16-event sequences balanced for 3- and 4-tuple frequencies, respectively. Thus, due to the 4-tuple balance in Table 6, each event class has been preceded by all 3-tuples, so that the effects of events on trials $n - 1$, $n - 2$, and $n - 3$ can be assessed. In general, this type of assessment can be performed for the $r - 1$ trials preceding the n th trial whenever r -tuple balance is achieved.

The programming logic employed in the generation of these sequences involved the systematic production of all possible sequences of the specified length. Following the generation of a sequence, an assessment was made for the appropriate number of 1s and 0s, and the numbers of r -tuples or overlapping subsequences of length r . Therefore, the tables should be exhaustive with regard to possible sets for the relevant characteristics in each case. (Note, however, Point 4 below regarding complements or mirror images of the tabled sequences.)

Various other factors governing use of the tables also deserve comment:

(1) Each r -tuple can be represented as a branch in a Markov diagram and each event in the trial block as the final event of such a branch. Therefore, the basic length of each trial block (i.e., prior to the addition of any "terminal events" which precede it) is related to some multiple of the number of branches that exist for a given subsequence length. Thus, for 2-tuples there are 2^2 , or 4, possible branches and the basic length of a balanced trial block must be some multiple of 4, e.g., 4, 8, 12, 16, 20, etc. For schedules balanced for 3-tuple occurrences, the basic trial block length is restricted to a multiple of 2^3 , or 8, while for length-4 subsequence balance, the basic trial block length must be a multiple of 2^4 , or 16.

(2) When several sequences are used in succession, the initial event(s) of a given sequence is/are normally the final event(s)

TABLE 5

SEQUENCE LENGTH = 16

SUBSEQUENCE LENGTH = 3

TERMINAL EVENTS OF PRECEDING SEQUENCE : 11

1. 1100101000011011	2. 0110010100001111	165. 0001000101101111	166. 0011110000101011
3. 1100011110100011	4. 0000100101110111	167. 1011101001000011	168. 1101101001000011
5. 0001011110001011	6. 1000011100001011	169. 1100010100010111	170. 1011000010100111
7. 0000100111101011	8. 1000100010111011	171. 0000101110100111	172. 1010000101110011
9. 1000110100010111	10. 1101001100001011	173. 1010010000111011	174. 1011010001000011
11. 0011000010101111	12. 0100010001111011	175. 1010100111000011	176. 0111010001000111
13. 0010000101110111	14. 0111100001001011	177. 0100111010000111	178. 1001110101000011
15. 0011101010001111	16. 0000101111010011	179. 0100010100011111	180. 1101101000100011
17. 1011010000100111	18. 1000101000111011	181. 1010111000100011	182. 1010000100111011
19. 1011000010010111	20. 0100100001110111	183. 0001011000101111	184. 0001011100010111
21. 1100100001101011	22. 0100100001110111	185. 0101000111000111	186. 0101110010000111
23. 0111010001000111	24. 1010011100001011	187. 0010100001011111	188. 1010001100010111
25. 1010100110000111	26. 1101010001100011	189. 1100110001010111	190. 0100111000010111
27. 1100101100001011	28. 0100001011001111	191. 0011100001010111	192. 1000011101010111
29. 0100010001110111	30. 0110100100001111	193. 0100011110010111	194. 1001011010000111
31. 1001000010101111	32. 1101000100110111	195. 1101010000100111	196. 1000101101000111
33. 1000010100111011	34. 0101100010001111	197. 0110010100011111	198. 0110001010001111
35. 1000010001010111	36. 0001100010101111	199. 1010111000010011	200. 0010110000101111
37. 0000110010101111	38. 0010111101000011	201. 1101000101100011	202. 1100001100101011
39. 0100111100001011	40. 1010001000111011	203. 0101111000010011	204. 0101001100001111
41. 0010000101101111	42. 1000011100101111	205. 1000101000101111	206. 0110100001001111
43. 0010101110000111	44. 1000010010111011	207. 0001101000101111	208. 1101000110100011
45. 1101000100010111	46. 0100011101000111	209. 1101001101000011	210. 0010110000101111
47. 1100010001010111	48. 1000100011101011	211. 1011000100010111	212. 0000100111010111
49. 1101000010100111	50. 1101000010110011	213. 1010011101000011	214. 110001100001010111
51. 1001010110000111	52. 1010000101100111	215. 1000101110001011	216. 0101000100001111
53. 1010100001100111	54. 0100001011110011	217. 0100101111000011	218. 1011100010100011
55. 1100001010100111	56. 0000111010010111	219. 1010000100110111	220. 1010001010000111
57. 0000101001010111	58. 1101100100001011	221. 1100101011000011	222. 1001100001010111
59. 0001111010100011	60. 1000101011000111	223. 1011100101000011	224. 0100001001101111
61. 1101010011000011	62. 0000100110101111	225. 0111000101000111	226. 1011101000100011
63. 0100010001011111	64. 1000101110100111	227. 1000010011101011	228. 0100010111000111
65. 1000010110000111	66. 0010101111000011	229. 0111001010000111	230. 1000110001010111
67. 0000101011100111	68. 1001101010000111	231. 0001000101110111	232. 0111101001000011
69. 1010000111001011	70. 0000110101001111	233. 0001111000101011	234. 0010111000010111
71. 1001010000111011	72. 0010000101110111	235. 0000111001010111	236. 1000111000101011
73. 1000010111100111	74. 0110000100101111	237. 0000111101010011	238. 1010000110001111
75. 0101000111100011	76. 0011010100001111	239. 1101000011001011	240. 0010000111010111
77. 1100011010100011	78. 1000011010100111	241. 1000100010110111	242. 0100111101000011
79. 0011010000101111	80. 0100001100101111	243. 1010010000101111	244. 0000101011110011
81. 1000101011100011	82. 0101000011100111	245. 0110100010001111	246. 100111101000010111
83. 0000101111001011	84. 0101001110000111	247. 1000010101100111	248. 0101111000100011
85. 1000011100101011	86. 1100001101001011	249. 0001000101111011	250. 1001011000010111
87. 1010100001110011	88. 1100001001101011	251. 1010001111000011	252. 1101100010100011
89. 0000101100011111	90. 1000010101110011	253. 1010100001000111	254. 1010111001000011
91. 1001010000101111	92. 0000101001110111	255. 0111101000100011	256. 0111010000100011
93. 0101100100001111	94. 1101100001010011	257. 0101000010011111	258. 1100001101010011
95. 0111100010001011	96. 0001010001110111	259. 1010110000100111	260. 0111100001010011
97. 1100011010001011	98. 1010110010000111	261. 0101000110011111	262. 1101000110001011
99. 1000010111010011	100. 1010011010000111	263. 0001110100010111	264. 0101110001000111
101. 0110001000101111	102. 1101001011000011	265. 1011100001001011	266. 0111001000010111
103. 0000101111001011	104. 0000100101101111	267. 1001010000101111	268. 1001110000101011
105. 0010100001110111	106. 0001010111100011	269. 0100010110001111	270. 0001011101000111
107. 1001010111000011	108. 0100001011100111	271. 1010010110000111	272. 0001110001010111
109. 1100010101000111	110. 0100001100101111	273. 1010010111000011	274. 1011100101000011
111. 0001000111101011	112. 0101000011100111	275. 1011001010000111	276. 0010000111101011
113. 1011000100010111	114. 0100110100001111	277. 0000111100101011	278. 0100010001111011
115. 1000011010010111	116. 1100001001010111	279. 1101100010001011	280. 0100001111010011
117. 1100010110001011	118. 1010001110001011	281. 1001011101000011	282. 0000101011001111
119. 1011100100001011	120. 0110001000101111	283. 0101011000011111	284. 1001000011101011
121. 0001000110101111	122. 0101001111000011	285. 0000111101001011	286. 1000010011010111
123. 1100100001010111	124. 0001010001101111	287. 0110000101001111	288. 0111101000010011
125. 1100101010000111	126. 0001010110001011	289. 1011101000010011	290. 1000001010011111
127. 0011101000010111	128. 0100100001101111	291. 0000101001111011	292. 1011010001000111
129. 1000111010001011	130. 1010000110100111	293. 1000010111001011	294. 0010100011101111
131. 0001010100011111	132. 0100011000101111	295. 0100010001111111	296. 0001011110100011
133. 0100001010001111	134. 1000100011010111	297. 1010100011100011	298. 0001111010001011
135. 0011110100001011	136. 1010010000101111	299. 0101110000100111	300. 1001000010111011
137. 1000011101001011	138. 1000110101000111	301. 0001101010001111	302. 1100001011010011
139. 1000111010100011	140. 0001000111010111	303. 1010011000010111	304. 1000011001010111
141. 0000100101111011	142. 0011110101000011	305. 0000111010001011	306. 1000010001010111
143. 0100101110000111	144. 1010001011100011	307. 1100001011001011	308. 1000101100010111
145. 0000101001111111	146. 0111000010010111	309. 1010111000100011	310. 1001000011010111
147. 1011000010100111	148. 1001011100001011	311. 1010110001000111	312. 0001010111000111
149. 1010001000101111	150. 110001011101000111	313. 0010111010001011	314. 0010000110101111
151. 0101011000001111	152. 0010111100001011	315. 1101011000100111	316. 110101100010000111
153. 0101000011001111	154. 1100110100001011	317. 0100001110100111	318. 0100011110001011
155. 0100110000101111	156. 1100010001010111	319. 1010000111010011	320. 0111100100001011
157. 0100010001110111	158. 1100110101000011	321. 0100010111100011	322. 1011000101000111
159. 1101000011010011	160. 1100001010010111	323. 1011001000010111	324. 0111000101000111
161. 0001110100001111	162. 1010001011000111		
163. 0001010001111011	164. 0000101100101111		

TABLE 5 (CONT'D)

SEQUENCE LENGTH = 16

SUBSEQUENCE LENGTH = 3

TERMINAL EVENTS OF PRECEDING SEQUENCE : 10

1. 1101111000100010	2. 1000010111100110	165. 0011010111010010	166. 000101010110010
3. 010111101000010	4. 0001110100111010	167. 0011101000101110	168. 001010001110110
5. 0001010010101110	6. 0001100101111010	169. 0101101011000010	170. 1110100111000010
7. 0101110000101010	8. 0111010000111010	171. 0001010111001110	172. 0101010000011110
9. 010111100001010	10. 0101111010000110	173. 1001110100001110	174. 000111001010110
11. 1101001000011110	12. 111010000110010	175. 0001001110101110	176. 1001110100001110
13. 100001011110010	14. 0001010011101110	177. 000100111010110	178. 000111001011010
15. 100001001111010	16. 0001111001101010	179. 0101000011101010	180. 100110000111010
17. 1010001000011110	18. 1110001011100010	181. 0101000011101010	182. 0110100001011110
19. 0010111011100010	20. 1100010001111010	183. 100011011100010	184. 0010111000101110
21. 0011101000101010	22. 0011100010101110	185. 1110010000101110	186. 0011101000101010
23. 100101111000010	24. 111000011010010	187. 001110001010110	188. 1010000100111110
25. 000101111010010	26. 1110001110001010	189. 000101001111010	190. 0001011000101110
27. 100111000010110	28. 010111011000010	191. 0010111010001110	192. 1000110001011110
29. 101000010011110	30. 0001100111101010	193. 1001100001111010	194. 0111101000011010
31. 0011101000111010	32. 1100011110100010	195. 1111010011000010	196. 0111100100001110
33. 100110100011110	34. 1110000101001010	197. 1011100010001110	198. 1110010000111010
35. 1000110100011110	36. 1110001000101110	199. 110011101000010	200. 1110001010001110
37. 1110001010001110	38. 1010011000011110	201. 101110011000010	202. 0001101001111010
39. 1000011110101010	40. 111000110100010	203. 1110001000101010	204. 0001001101111010
41. 110001001111010	42. 1110100001110010	205. 100010111100010	206. 1100111100001010
43. 1110001110100010	44. 1110010000101110	207. 1000010011101110	208. 100001110100010
45. 0010110001111010	46. 0001110011101010	209. 001110101000110	210. 0101110000101110
47. 111010001000010	48. 0111010101000010	211. 0001010100011110	212. 1011000100011110
49. 000101111010010	50. 0011000101011110	213. 1110100100001110	214. 0001010100011110
51. 110001111000010	52. 1110111000010010	215. 0110101000011110	216. 0001000101011110
53. 001011100001010	54. 0001011110010110	217. 0001010101110010	218. 1011000010001110
55. 1110000100011110	56. 0111100001010110	219. 101000111100010	220. 0111000011101010
57. 1111001000011110	58. 0010100011101110	221. 011100001011010	222. 101100001110010
59. 0101000011101110	60. 0001010111010010	223. 000111101010010	224. 100110111000010
61. 0010100001111110	62. 1010001000011110	225. 111000101100010	226. 1001000110111110
63. 0001010111101010	64. 0101011100001110	227. 0001011110001010	228. 0001110001010110
65. 0001010111101010	66. 0001011001011110	229. 1000100001011110	230. 001000111101010
67. 1100010111100010	68. 0001111011001010	231. 001010111100010	232. 110100111000010
69. 1000111000101110	70. 1000111101000110	233. 0001101010001110	234. 0010001110101110
71. 0001110010101110	72. 110000111001010	235. 0010101110001110	236. 011110001100010
73. 1110001000111010	74. 1010011110001110	237. 1000010101011110	238. 1000011001011110
75. 0010001010111110	76. 0011110001011010	239. 101100001110010	240. 110011101000010
77. 1000011110100010	78. 1000011110100110	241. 111001100001010	242. 0010110100001110
79. 1110010100011110	80. 0100001010111110	243. 001100011101010	244. 1100010100001110
81. 0001110111010010	82. 1110111001000010	245. 111010000101010	246. 1110100001001110
83. 0010100111100010	84. 111001101000010	247. 1110100010001110	248. 0010001010111110
85. 0010101000111110	86. 1110000111001010	249. 1110100011100010	250. 1101111001000010
87. 1001111011000010	88. 1111011000010010	251. 0001010101110010	252. 011010111000010
89. 100111100001010	90. 0011110110100010	253. 1000100011101110	254. 1100010000101110
91. 0001111010100010	92. 1110010000101010	255. 1000011101110010	256. 000101110001010
93. 1000111010001110	94. 1110000100111110	257. 0111000011101010	258. 1000011001101010
95. 1001000010101110	96. 1100001011100010	259. 1011100111000010	260. 101100111000010
97. 1111000010100010	98. 1011110010000110	261. 1010000111001110	262. 1000010011101110
99. 001000010111010	100. 001111010100010	263. 001011110100010	264. 1001011000011110
101. 010000101011110	102. 101110000100010	265. 1100001001011110	266. 0010001011110110
103. 001011000111010	104. 0101110100001110	267. 000111011100010	268. 1000111000111010
105. 1100010001011110	106. 0101100001111010	269. 1011110000110010	270. 010110000111010
107. 101100011100010	108. 0001001011101110	271. 0101101000011110	272. 1111000010010110
109. 111100001100010	110. 000111101001010	273. 0100001010111110	274. 100111011000010
111. 0100001011101010	112. 1110000100111010	275. 0011101100001010	276. 0011010001111010
113. 001000111011010	114. 001101110100010	277. 1001000011101010	278. 0010001110101110
115. 1000011100011110	116. 0001001111010110	279. 1000101111000010	280. 0100001110101110
117. 0010100011101110	118. 0010101000011110	281. 0111000010101010	282. 1100001010011110
119. 00011100101100010	120. 1011100001001110	283. 0101010000101110	284. 100001111001010
121. 0001010001010110	122. 111100001010010	285. 1101000100011110	286. 1010011100001110
123. 0010001110101110	124. 0111000010101110	287. 010101111000010	288. 0001000101011110
125. 001011110001010	126. 001011110100010	289. 1100001001011110	290. 010000111011010
127. 1000010010111110	128. 1000001110111110	291. 0101000010111110	292. 011010111000010
129. 0011110000101010	130. 1000011100011110	293. 0010100010111110	294. 0001001101011110
131. 1000100011101010	132. 1001110000101110	295. 101000111100010	296. 100011110001010
133. 0001011100111010	134. 1010001110001110	297. 110001100001010	298. 0011000010111010
135. 1110000111001010	136. 1000011110010110	299. 0001100100011110	300. 1110111000100010
137. 1000101110001110	138. 011101100001010	301. 000111010100010	302. 1110100100001110
139. 1000001111001110	140. 1000101000011110	303. 0111010000101010	304. 0111010000101010
141. 1000111000011110	142. 1000011110011110	305. 1000110001111010	306. 010000110111010
143. 0001011100011110	144. 1111011000100010	307. 0100001111101010	308. 0011010100011110
145. 0101011100001110	146. 0001011101001110	309. 101000111100010	310. 0001010001101110
147. 1001100001011110	148. 0010111100010110	311. 1100101000011110	312. 0100001011101110
149. 0111010100001110	150. 0101110000101010	313. 1101111000010010	314. 011101101000010
151. 0001111010001110	152. 110010111000010	315. 0010001011101110	316. 0110100001011110
153. 111101000100010	154. 0010110111000010	317. 110010000111010	318. 111000101000010
155. 1110001011100010	156. 1111000100001010	319. 1111000010101010	320. 1100001110100010
157. 1000111100010110	158. 1000011110100110	321. 0100001111010110	322. 001000101111010
159. 000100111101010	160. 1110000101110010	323. 011101011000010	324. 001101011100010
161. 001101110001010	162. 0101000110111110		
163. 011000010111010	164. 110100011110010		

TABLE 6

SEQUENCE LENGTH = 16

SUBSEQUENCE LENGTH = 4

TERMINAL EVENTS OF PRECEDING SEQUENCE : 111

1. 0101100100001111	2. 1000010011010111
3. 0010110100001111	4. 0101100001001111
5. 0100001011001111	6. 1001101000010111
7. 0010100001011111	8. 1011000010100111
9. 1010000110010111	10. 1001000011010111
11. 0100110000101111	12. 0000101101001111
13. 1010011000010111	14. 1010110000100111
15. 0011010000101111	16. 1000011010010111
17. 0110000101001111	18. 0000110100101111
19. 0100101100001111	20. 0110010100001111
21. 1000010110001111	22. 1011001010000111
23. 0100001001011111	24. 1010110010000111
25. 1001011010000111	26. 1010010110000111
27. 0010000110101111	28. 1001010000110111
29. 0000101001101111	30. 1000010100110111
31. 1010000101100111	32. 0000100110101111

TERMINAL EVENTS OF PRECEDING SEQUENCE : 110

1. 1001011000011110	2. 0101111010000110
3. 1011110010000110	4. 1011110000100110
5. 1001011110000110	6. 1111000010100110
7. 0101101000011110	8. 0101000011101110
9. 1000011110010110	10. 0101000011011110
11. 0001111010010110	12. 1001100001011110
13. 1011001000011110	14. 0001010011011110
15. 0001010011101110	16. 0110100001011110
17. 1000010110001110	18. 1000010111001110
19. 1011000010011110	20. 0001001101011110
21. 0111101000010110	22. 0001011110100110
23. 1111001010000110	24. 1100101000011110
25. 0001011010011110	26. 1000011001011110
27. 0001001111010110	28. 0100001010111110
29. 1100001010011110	30. 0001010010111110
31. 0100001111010110	32. 1001111000010110

TERMINAL EVENTS OF PRECEDING SEQUENCE : 101

1. 1110100001100101	2. 1110000100110101
3. 0011000010111101	4. 1110000101001101
5. 0110000100111101	6. 0011110110000101
7. 1001010000111101	8. 0010111100001101
9. 1000010011110101	10. 1110100110000101
11. 1010000111100101	12. 1001000011110101
13. 0000111101100101	14. 0111100001001101
15. 0010110000111101	16. 1110010000110101
17. 0011110000111101	18. 0011011110000101
19. 0000101111001101	20. 0110010000111101
21. 1110011000010101	22. 0111100100001101
23. 0000101100111101	24. 0000101111001101
25. 1110010100001101	26. 0000111100110101
27. 0000110010111101	28. 1000011110100101
29. 1000010100111101	30. 1110000110100101
31. 1001111010000101	32. 1010011110000101

TERMINAL EVENTS OF PRECEDING SEQUENCE : 100

1. 0011110101100100	2. 1011000011110100
3. 1000011010111100	4. 0010100110111100
5. 1101011110000100	6. 0010100101111100
7. 1010000111100100	8. 0010111100110100
9. 1100001011110100	10. 0010011010111100
11. 1101111000010100	12. 1110110000101000
13. 0011110110010100	14. 0010111101001100
15. 1101000010111100	16. 1011110000110100
17. 0010110100111100	18. 0010111100101000
19. 1111000010110100	20. 0010100111101000
21. 1110101100001000	22. 1110100001011000
23. 0011110100101100	24. 1010000110111000
25. 0011110010101000	26. 1011110100001100
27. 1000011110101000	28. 1011010000111000
29. 0010011110101000	30. 0011001011110100
31. 0011010111101000	32. 0010110011110100

of the r -tuple(s) begun in the block preceding it and, therefore, the r -tuple distribution for a trial block is contingent upon the terminal event(s) of the preceding block. Consequently, all sequences are listed in terms of those appropriate following specific terminal events of the preceding sequence. For 2-tuple balance, it is necessary to take into account only the single terminal event of the preceding block, whereas the final two events must be considered for 3-tuple balance, etc.

Of course, in some experimental contexts in which blocks of trials are separated by long periods of time, independence between trial blocks may be postulated and series may be chosen without regard to preceding blocks. In order to obtain all possible r -tuples in such situations, it is necessary to lengthen each basic block by preceding it with appropriate events chosen from the terminal events section.

(3) Directly related to the latter point of (2) above, if all trial blocks in an experiment are to be submitted to sequential analysis, the first complete block of trials must be preceded by an appropriate set of events chosen from the

terminal events section. For example, if an experiment involves five interrelated trial blocks of length 8 balanced for 3-tuple occurrences, and if the first block is to be submitted to sequential analysis, the experiment will consist of 42 trials: the initial two trials of the experiment (which are not analyzed but provide the starting points for 3-tuples terminating in the first complete block) and five blocks of 8 trials each.

(4) Since each sequence, along with its appropriate terminal events, has a complement or mirror image (e.g., 1011 is the mirror image of 0100), only half of the possible sequences are actually presented in these tables. Omissions were made on the basis of the terminal events of preceding sequence classifications with only those terminal events sections starting with 1 included in the tables.

(5) If an experiment involves a succession of interrelated as opposed to independent blocks, once it is initiated in a given terminal events section it will remain in that section for its duration, i.e., the terminal events for each block are the same across all blocks. This, of course, results in differences in the average placement values

of the various r -tuples that cannot be eliminated on a within-Ss basis, as well as trial-by-trial probabilities for each event class which deviate from .5 within each terminal events section. As can be seen in Table 7, the relationships between these probabilities and trials are quite complex and, hopefully, will not be reflected in behavioral fluctuations in most experimental contexts. Any standard counterbalancing strategy in which equal numbers of Ss are given schedules from all possible terminal events sections, including those which are complementary to the sections appearing in the present tables, will result in comparable placement values for r -tuples and trial-by-trial probability values of .5 when averaged across Ss. Similar counterbalancing techniques, of course, would have to be employed with any method of schedule generation if comparable placement values were achieved for each trial block.

(6) Within a given terminal events section, the ordering of the sequences was determined by a computer program which assigned a random number to each sequence. The numbers appearing to the left of the sequences represent the ordinal

Table 7
Probabilities of a 1 Occurrence for Each Trial Related to Sequence and Subsequence Lengths and Terminal Events of Preceding Block*

Table	Sequence Length	Sub-sequence Length	Terminal Events	Trial															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4	2	1	0.50	0.00	0.50	1.00												
2	8	2	1	0.50	0.33	0.39	0.56	0.39	0.33	0.50	1.00								
3	8	3	11	0.50	0.25	0.25	0.25	0.25	0.50	1.00	1.00								
			10	0.50	0.25	0.75	0.25	0.75	0.50	1.00	0.00								
4	12	2	1	0.50	0.40	0.44	0.48	0.47	0.42	0.47	0.48	0.44	0.40	0.50	1.00				
5	16	3	11	0.50	0.42	0.33	0.42	0.46	0.42	0.45	0.45	0.42	0.46	0.42	0.33	0.42	0.50	1.00	1.00
			10	0.50	0.42	0.50	0.58	0.46	0.50	0.53	0.47	0.50	0.54	0.42	0.50	0.58	0.50	1.00	0.00
6	16	4	111	0.50	0.25	0.44	0.28	0.41	0.47	0.31	0.47	0.41	0.28	0.44	0.25	0.50	1.00	1.00	1.00
			110	0.50	0.38	0.25	0.72	0.34	0.47	0.62	0.28	0.59	0.41	0.19	0.75	0.50	1.00	1.00	0.00
			101	0.50	0.38	0.62	0.28	0.47	0.59	0.31	0.59	0.47	0.28	0.62	0.38	0.50	1.00	0.00	1.00
			100	0.50	0.25	0.81	0.59	0.41	0.72	0.38	0.53	0.66	0.28	0.75	0.63	0.50	1.00	0.00	0.00

*In each case the use of all terminal events sections, including complements to those tabled, will result in trial-by-trial probabilities of .5 when averaged across Ss.

positions which resulted and can be used as the basis for selection by means of a lottery technique or a table of random numbers.

DISCUSSION

Use of the present tables represents one of several approaches to developing schedules for psychological experiments in which two-class events are presented. The unique properties which these schedules possess are that equal numbers of the possible overlapping subsequences, or r-tuples, occur within each trial block. Various other methods of schedule generation will result in such characteristics with varying degrees of success.

A method used frequently is the random generation of events within restrictions of equal occurrences of the two classes of events within a trial block of specified length. Since the present sequences represent subsets of such series, it is obvious that r-tuple balance will occur with low probabilities when trial blocks are generated in this manner. For example, for 2-tuple balance probability values of .333, .257, .219, and .190 are obtained for trial-block lengths of 4, 8, 12, and 16, respectively. With regard to 3-tuple balance, values of .057 and .025 are obtained for trial-block lengths of 8 and 16, with a value of .002 occurring for 4-tuple balance of randomly generated 16-trial blocks having equal occurrences of the two event classes.

While a random method of schedule generation results in low probabilities of r-tuple balance, use of the Gellermann series will never result in equal r-tuple representation, due to the fact that each series contains 10 events. As discussed earlier, a basic requirement for such balance is that a trial block must be some multiple of a basic 2^r unit, where r represents the tuple length.

A method that will result in trial blocks balanced for 2-tuple occurrence is that involving an equal number of runs of

lengths 1, 2, and 3 of each class of event. However, while this method will ensure balance for trial $n - 1$, or 2-tuple occurrence, when transitions occur at the junction of two blocks, these schedules are biased such that all overlapping subsequences having opposite first and third events (i.e., 110, 100, 001, and 011) necessarily occur with greater frequency than do those 3-tuples that have identical first and third events (101, 111, 010, and 000). This means that the probability that trials n and $n - 2$ are of the same class is less than .5. While some schedules in the present tables contain a similar bias (i.e., balancing for r-tuples means that only the effects of the $r - 1$ trials preceding the n th trial can be assessed without possible bias), it is possible to select schedules from these tables which take into account the specific $n - 2$ bias of the type under discussion.

There are two ways in which sequential bias of the type currently under discussion might be important in a given experimental context. In the first place, the possibility exists that the S may learn to respond congruent to this pattern during the course of the experiment, in which case measures of differential responding, etc., might be influenced. Second, it may be desirable and/or necessary to take into account possible reinforcement effects of preceding trials on trial n . Indeed, existing data in differential eyelid conditioning with human Ss suggests that such effects (specifically for $n - 2$ effects) might be pronounced (Vandament, 1970). Therefore, the possibility exists that use of schedules biased in this regard as a result of balancing for run length could lead to lower apparent levels of differentiation than could use of schedules not characterized by this bias.

The relation of run length to r-tuple balancing can be more fully appreciated when one considers the restrictions concerning runs which necessarily accompany r-tuple balance. Such restrictions lead to some bias concerning

run lengths in the present tables. First, the maximum run length of a given event within a trial block is related to the length of the r-tuple for which balancing has occurred and to the length of the trial block. If the basic 2^r unit is utilized as the trial block, the maximum run length within a block is necessarily the length of the defined r-tuple. Note, however, that run lengths greater than r can occur at the junction of two trial blocks within the larger context of a total experiment. If some multiple of the basic 2^r unit is employed as a trial-block length, then the maximum run length within a trial block can be increased by 1 for each multiple greater than 1. For example, in Table 1 2-tuple frequency in a four-trial block is balanced, and runs of length 2 are the maximum observed within a trial block. In Table 2 trial blocks of length 8 are balanced for 2-tuples, and a maximum run length of three can occur within a trial block.

Furthermore, the probabilities associated with runs of certain lengths less than the maximum are also relatively low in some of the schedules due to the relationships between r-tuple patterns and run lengths and to the lack of independence which necessarily exists between the ordering of r-tuples. For example, a run of length 2 occurs only when the 3-tuples, 100 and 001, are adjacent and thus form the event sequence 1001. For that case in which each 3-tuple occurs once (i.e., the sequence of length 8 balanced for 3-tuple frequency, Table 3), the 3-tuple 000 is necessarily bounded by 100 and/or 001, and thus the possibility of a run of length 2 within the trial block is precluded. Similarly, runs of length 3 do not occur within the trial block when 16-trial sequences are balanced for 4-tuple frequency and maximum run length is 4. Such runs of intermediate length can appear occasionally at the junction of two trial blocks within the context of a multiblock experiment, but they are, of

course, characterized by relatively low probabilities of occurrence.

The significance of these sources of bias related to run length will necessarily be determined empirically for various experimental contexts. It should be noted, however, that (1) restrictions on maximum run length are also characteristic to some extent of all alternative methods of schedule generation described previously, and (2) any schedule that is balanced for run-length frequency will also contain some bias with regard to r-tuple occurrence which is more restrictive than the similar, but in some cases avoidable, bias which is inherent in the present schedules.

Finally, consideration should be given to alternation behavior, although the present sequences were not developed to deal specifically with such problems and not every sequence listed will yield a chance score of .5 when the S displays a single- or double-alternation pattern. The authors are not aware of any published sets of events in which each series will result in a .5 "correct" probability associated with either type of alternation behavior. In the Gellermann series, a single-alternation pattern of behavior will result in a "correct" proportion of either .6 or .4, depending upon the nature of the initial response. Double-alternation behavior can result in "correct" proportions of .9, .7, .5, .3, or .1 for the Gellermann series. Summed across all possible sequences, "correct"

probabilities of .5 are characteristic of both the Gellermann and the present sequences. Since a few of the present sequences have been found to yield "correct" scores of .5 for both single- and double-alternation patterns, the authors are presently attempting to survey the present tables for sets of sequences having the desired properties.

CONCLUSIONS

The preceding assessment of existing methods for generating schedules of two-class events indicates that not all desired features can be assured in any given schedule, e.g., r-tuple balance and equal representations of various run lengths cannot occur in the same schedule, and a random method of generation will rarely result in r-tuple balance. Therefore, the E must determine in each case which properties are expendable and which are essential. However, it would appear crucial that the nature of schedule generation be reported in detail and desirable that standard schedule properties exist for some experimental areas in order to facilitate comparisons of results. In those contexts in which behavior has been demonstrated to be a function of immediately preceding reinforcements and nonreinforcements, the present schedules would appear to possess characteristics relevant to such standards.

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NOTES

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2. Presently at Massachusetts Institute of Technology.