Effect of presentation order on the construction of linear orders

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Subjects constructed four-term linear orders from three sentences expressing the relationships between adjacent elements in the order. Successful performance was more likely when the second sentence introduced only one element not mentioned in the first sentence rather than two new elements and when the second and third sentences introduced new elements as grammatical subjects rather than objects. Except for the latter result, previously proposed theories of reasoning processes primarily in three-term series problems, predict other differences that failed to appear. Apparently, in longer series, memory limitations favor conditions in which each sentence after the first presents a relationship between a new and an old element in linguistic forms that identify the new element.

A number of recent studies have shown that when a subject is asked to learn or remember a set of sentences that describe a linear ordering, what is remembered is the ordering rather than the individual sentences (Barclay, 1973; Potts, 1972). For example, when presented with the sentences, "The bear is smarter than the hawk, the hawk is smarter than the wolf, and the wolf is smarter than the deer," subjects construct and retain the following linear order: bear, hawk, wolf, deer. The evidence for the foregoing hypothesis consists of two types of findings. Potts (1972) showed that subjects who had studied sentences such as those given above were faster and more accurate in judging the truth of sentences describing nonadjacent members of the order, e.g., "The bear is smarter than the wolf," which they had not seen before, than in judging comparable sentences describing adjacent members, e.g., "The bear is smarter than the hawk," which they had seen. Barclay (1973) showed that subjects who had learned a set of sentences derived from a five-term linear ordering responded in a sentence memory test solely on the basis of whether the sentences were true of the the ordering as opposed to their actual presence on the learning list. The best explanation of these findings is to assume that subjects construct their own linear array and respond to test items on the basis of whether the item is true or false of the array.

Although a great deal of effort and discussion has been devoted to discovering the exact nature of the subject's mental representation of the order (Barclay & Reid, 1974; Potts, 1974; Scholz & Potts, 1974), somewhat less attention has been given to the question of how the mental ordering is constructed, and very

little research has been conducted to determine what variables influence these constructive processes. Barclay (1973) has shown that instructions to the subjects can influence to some extent whether or not the linear order is constructed. But in cases where it is clear that subjects are engaged in constructing a linear order, there remains the question of how the constructive process operates. More to the point, Potts (1972) found that overall performance was poorer for subjects who received as input a compound sentence in which the surface order of the elements did not reflect the linear order. If the component simple sentences are represented in the form $A > B$ (which might, for example, stand for, "The bear is smarter than the hawk"), then subjects who received the input, $C > D$, $A > B$, $B > C$, made more errors and apparently responded more slowly than subjects who received the input, $A > B$, $B > C$, $C > D$. (Potts did not report the reaction time comparison of these two groups.) The differences produced by input orders suggest that variations in input order may be a useful tool for exploring constructive processes.

The present study is concerned with the effects of different input orders on success in constructing linear orders. In two experiments, subjects listened on each trial to a set of three sentences and then, when signaled that the series was complete, wrote down the four terms in the order described by the sentences. In a four-term series problem there are six different ways in which the three input sentences can be ordered (see Table 1). The six orders differ in a number of ways that might be important for the process of constructing the underlying order. For example, Potts (1972) suggested that his Group 1, which received Order 6, had difficulty because the order of presentation did not reflect the underlying linear order, whereas his Group 2, which received Order 1, performed better because the surface order in this case corresponds with the order to be constructed.

We wish to thank Donald A. Brown Jr., Barbee T. Mynatt, and Mark A. Sabol for their advice and comments on an earlier version of this paper. Requests for reprints should be sent to Kirk H. Smith, Department of Psychology, Bowling Green State University, Bowling Green, Ohio 43403.

Although the notion of correspondence between surface and underlying order has intuitive clarity in comparing Orders 1 and 6, the concept is not specified enough to permit unambiguous predictions. Consider Order 2, in which the pairs of adjacent elements in the series are presented to the subject in reverse order. Should this order be treated as completely lacking correspondence, or should it be analyzed as a relatively simple transformation of the order to be constructed? Similarly, Order 5 can be analyzed as a good reflection of the order to be constructed because the first two sentences present all four elements of the series in the order to be constructed, and the last sentence merely confirms the implied ordering. Clearly, Order 5 is a better reflection of the underlying order than Order 6, in which the first two sentences present the four elements of the array in an order different from the one the subject must ultimately give. Although the definition of correspondence between order of presentation and order to be constructed requires more specification, the weakest interpretation of a *correspondence hypothesis* would predict at least that Order 2 would be more difficult than Order 1 and that Order 6 would be more difficult than Order 5.

Other differences exist among the six orders shown in Table 1. Orders 1, 2, 3, and 4 differ from Orders 5 and 6 in whether the first two sentences introduce three or four elements. In the latter two orders, the second sentence introduces two new elements. Neither element matches the elements introduced in the first sentence. The subject cannot construct with certainty any order beyond the two-term orders of the sentences. Suppose that instead of constructing a tentative order as suggested above, the subject attempts to hold the two sentences independently in memory. Moreover, if the constructive process does not begin until after the third sentence is presented, then three independent sentences would have to be retained and integrated. However, in Orders 1, 2, 3, and 4, the second sentence can be integrated with the first to form a three-term series. Only the latter construction needs to be retained along with the third sentence while it is held and integrated. Thus, a *memory load hypothesis* predicts that Orders 5 and 6 will be more difficult than the other four orders.

Finally, among the four orders in which construction can begin reliably with the second sentence, Orders 1 and 2 differ from Orders 3 and 4 in that the former begin with a sentence containing an element at the end of the underlying array. These orders permit the subject to build, one step at a time, from one end of the array to the other. In Orders 3 and 4, subjects following a constructive strategy must begin in the middle of the array and build first toward one end point and then the other. If the end points of a linear order serve as anchors to which other elements are attached, then Orders 1 and 2 should have an advantage over Orders 3 and 4. Although we are obviously indebted to DeSoto, London,

and Handel (1965) for the *end anchor hypothesis*, their explanation of subjects' performance in the three-term series problem does not appear to fit the present experimental paradigm. Their theory of spatial paralogic assumes that the subject can visually scan both premises (and the question) to determine the end points of the array and then reconsider the premises (cf. Wason & Johnson-Laird's, 1972, treatment of the "image" theory of DeSoto et al.). Because our subjects were unable to determine with certainty which elements were the end points until all three sentences had been presented, the proposed end anchor strategy must be different in detail, if not in spirit, from the one proposed by DeSoto et al.

EXPERIMENT I

Method

Subjects. The subjects were 28 undergraduate students whose participation fulfilled a requirement in an introductory psychology course. Each subject received all treatment combinations.

Materials. On each of 24 trials, the subjects received a set of three sentences referring to an array of the following four elements: *doctor, farmer, soldier, teacher*, all of which were named by two-syllable, high frequency nouns (Thorndike-Lorge AA words). Each sentence had the form, "The A is X-er than the B," where A and B were adjacent array elements and X was one of two adjectives, *tall* or *short*. Each subject received a block of 12 trials in which all sentences contained *taller* and another block of 12 trials in which all sentences contained *shorter*. Each of the six orders shown in Table 1 was presented twice in each block of 12 trials. Assignment of orders to trials within the blocks was random. Array elements were also randomly assigned to a different linear order on every trial. Half of the subjects received a block of 12 trials with *taller* sentences first, and half received a block containing *shorter* sentences first.

Procedure. All subjects were tested in small groups until 14 had received a block of *taller* sentences first and 14 had received a block of *shorter* sentences first. The subjects were instructed to listen to three sentences which described an array of elements and, after the last sentence, to write down the ordered array on a response sheet. The response sheet provided a column for each trial headed by the superlative form of the adjective used in the sentence (*tallest* for trials using *taller* sentences and *shortest* for sentences using *shorter*), followed by four numbered lines for the array elements, followed at the bottom by the superlative form of the other adjective. The experimenter sat facing the subjects and read the sentences with normal intonation from a prepared script at the rate of one sentence every 5 sec, paced by a visual and auditory signal from a Hunter timer (Model 111-C). Immediately after the third sentence, the experimenter said "Recall," and then paused 20 sec before starting the next trial. All subjects completed recall within this intertrial interval.

Results and Discussion

The principal measure of performance was the proportion of correct linear orderings produced. The obtained values for presentation orders and adjectives are shown in Table 1. The subjects were on the average twice as likely to get the correct linear orders with Order 1 as with Order 6. There were no significant interactions involving the six input orders. A planned comparison showed that the two orders in which neither

Table 1
Mean Proportion of Strings Correctly
Constructed in Experiment I

Presentation Order*	Adjective		Overall Mean
	Taller	Shorter	
1. AB, BC, CD	.77	.57	.67
2. CD, BC, AB	.73	.45	.59
3. BC, CD, AB	.63	.52	.57
4. BC, AB, CD	.57	.52	.54
5. AB, CD, BC	.46	.41	.44
6. CD, AB, BC	.36	.32	.34

*For purposes of illustration, the subject's task in each case is to produce the series ABCD. The entry AB means either The A is taller than the B or The A is shorter than the B.

element in the second sentence corresponded to an element in the first sentence (Orders 5 and 6) produced significantly poorer performance than the remaining four orders [$F(1/130) = 31.20$, $p < .01$, $SE = .15$]. This comparison accounted for 81% of the variance due to orders. These results suggest that a major influence on constructive processes in four-term linear orders is whether or not one of the elements in the second sentence matches an element from the first sentence. The other four comparisons among input orders, corresponding to hypotheses discussed in the introduction, failed to reach significance, although the comparison of Orders 1 and 2 with Orders 3 and 4 (a test of the end anchor hypothesis) was marginally significant [$F(1/130) = 2.83$, $p < .10$, $SE = .08$].

A significant overall difference between the two adjectives was obtained [$F(1/26) = 13.82$, $p < .01$, $SE = .03$], as well as a significant interaction between adjectives and groups of subjects differing in the order in which the two adjectives were presented [$F(1/26) = 6.92$, $p < .05$, $SE = .03$]. The interaction appears to be due to the decreased performance in the first block when it was composed of sentences containing *shorter*. The obtained proportions for the first block were .38 for *shorter* and .59 for *taller*; comparable proportions for the second block were .55 for *shorter* and .58 for *taller*.

EXPERIMENT II

Although the results of the first experiment appear to indicate the importance of presentation order in the construction of four-term linear orders, the design also involves a confounding of presentation order with the grammatical status of new elements introduced in the second and third sentences. For example, in Order 1 the second sentence introduces an element of the underlying array not mentioned in the first sentence. This new element has the status of grammatical object in the sentence. Similarly, in the third sentence of Order 1, the fourth element in the array is introduced for the first time in the role of grammatical object. By contrast, in Order 2, the second and third sentences introduce new

elements as grammatical subjects. Orders 3 and 4 introduce one new element as the grammatical subject of a sentence and the other as a grammatical object. It follows that the results of Experiment I may merely reflect these variations in grammatical status within the input sentences.

There is a large body of data on the sources of difficulty found in solving three-term series problems (see Wason & Johnson-Laird's, 1972, review). Huttenlocher (1968) has suggested that performance on these problems is facilitated when the new element is presented as the grammatical subject of the second sentence as opposed to its grammatical object. (In fact, Huttenlocher argued that the crucial distinction is between logical subject and object, but for the sentences used in the present study the same word is both logical and grammatical subject; hence, the distinction is given here in terms of grammatical function.) While there has been some dispute about the adequacy of Huttenlocher's formulation (cf. Clark, 1969), the possibility of a confounding remains. If the grammatical status of the new element affects the difficulty of array construction, as Huttenlocher has suggested, then the results of Experiment I are inconsistent with the results for three-term series. Order 1 should have been more difficult than Order 2, and Orders 3 and 4 should have fallen midway between Orders 1 and 2. Alternatively, presentation order may have had a relatively larger effect on difficulty than the grammatical form of the input sentences, in which case the differences in difficulty among Orders 1, 2, 3, and 4 in Experiment I would have been reduced by the grammatical status effect. Obviously, the latter requires direct investigation.

The design of Experiment II permitted us to assess the effect of presentation order fully counterbalanced for grammatical status of new elements. All six presentation orders for four-term linear orderings were presented with all eight different combinations of two adjectives, *left* and *right*, in three sentences. Because the 32 treatment combinations involving Orders 1, 2, 3, and 4 can be classified (as shown in Table 2) in terms of the grammatical status of the new term in the second and third sentences, the design also makes possible a direct test of Huttenlocher's prediction that any combination of adjectives that introduces a new term as the grammatical object of the sentence should be more difficult than a comparable combination that introduces the new term as a grammatical subject. The pair of polar adjectives, *left* and *right*, was used because they are not differentially marked semantically (Clark, 1969).

Method

The subjects were 40 undergraduate students from the same subject population used in Experiment I. Procedure and materials were identical to those of the first experiment, with the following exceptions: The response sheet provided a left-to-right, horizontal array of four blanks bounded by the words *left* and *right* for each trial. Sentences had the form, "The

A is to the X of the B," where A and B were adjacent array elements and X was either *right* (R) or *left* (L). There are eight combinations of two adjectives in three sentences: LLL, LLR, LRL, RLL, LRR, RLR, RRL, and RRR. Each subject received 48 trials (six presentation orders combined with eight adjective combinations). Two random orders of the 48 trials were constructed. These orders were reversed to obtain two additional trial orders, for a total of four. Ten subjects were exposed to each trial order.

Results

The mean proportion of strings correctly constructed in each of the 48 treatment combinations is shown in Table 2. Planned comparisons among the presentation orders showed that 92% of the variance attributable to this factor was due to a comparison of the four match orders (Orders 1, 2, 3, and 4) with the two nonmatch orders (Orders 5 and 6) [$F(1/195) = 50.22$, $p < .01$, $SE = .09$]. The remaining comparisons among presentation orders were not significant. Comparisons of particular interest that failed to reach significance were the following: (a) The comparison between Orders 5 and 6, which tests one version of the correspondence theory, [$F(1/195) = 0.26$, $SE = .04$]; (b) The comparison of end-anchored orders (1 and 2) with non-end-anchored orders (3 and 4), [$F(1/195) = 0.52$, $SE = .05$]. The pattern of values for the overall proportion of correctly constructed arrays in the two experiments was very similar as evidenced by a significant rank order correlation between the two sets of six values [$\rho = .94$, $p < .05$].

The interaction variance was partitioned using planned comparisons of treatment conditions that differed in the grammatical status of the new term in the second and third sentences. When the last two sentences presented new items in subject position (Condition SS in Table 2), the mean proportion correct was .74, but when the new term was in object position in both sentences (Condition OO), the corresponding proportion was .59. These values were significantly different [$F(1/1365) = 19.78$, $p < .01$, $SE = .27$]. When one of the last two sentences presented a new term in subject position and the other presented a new term in object position, the mean proportion correct for Condition SO

was .61 and for Condition OS, .59. The latter values were not significantly different from each other [$F(1/1365) = 0.21$, $SE = .27$], but their mean was significantly less than would be expected if the effect of sentence form were additive [$F(1/1365) = 7.27$, $p < .01$, $SE = .39$]. Thus, it appeared that the presence of one sentence presenting a new term in object position was sufficient to disrupt array construction. A second such sentence apparently had no additional effect.

Huttenlocher's (1968) theory was also tested with a detailed analysis of the errors subjects made. The theory predicts that subjects should make more errors on the pair of elements that appear in a sentence that introduces a new element in object position. Errors for Orders 1, 2, 3, and 4 were therefore classified on the basis of which sentence contained the information that was incorrect in the constructed string. For example, if the presentation order was $A > B$, $B > C$, $C > D$, and the subject produced the order $C > D > A > B$, an error would be scored for the second input sentence, $B > C$. As predicted, more errors were attributable to sentences that presented new elements in object position [$F(1/117) = 14.65$, $p < .01$]. It also was possible in the foregoing analysis to cross-classify the error on the basis of which adjective the sentence contained. However, no difference was found [$F(1/117) = 2.34$].

CONCLUSIONS

The results of the present experiments are consistent in showing a large effect due to whether the second sentence in the presentation order introduces one or two new elements. Performance was always poorer on Orders 5 and 6, in which the second sentence contained two elements that did not match the elements of the first sentence. These results appear to support what we have called the memory load hypothesis. Apparently, an important source of difficulty in constructing a linear ordering is whether two independent relational sentences must be remembered. One clear line of future research concerns the understanding of this phenomenon.

Table 2
Mean Proportion of Strings Correctly Constructed in Experiment II

Presentation Order*	Adjective Combination								Overall Mean
	LLL	LLR	LRL	LRR	RLL	RLR	RRL	RRR	
1. AB, BC, CD	.78 ^{oo}	.70 ^{os}	.60 ^{so}	.80 ^{ss}	.63 ^{oo}	.58 ^{os}	.63 ^{so}	.70 ^{ss}	.675
2. CD, BC, AB	.68 ^{ss}	.68 ^{so}	.68 ^{os}	.58 ^{oo}	.65 ^{ss}	.53 ^{so}	.50 ^{os}	.63 ^{oo}	.612
3. BC, CD, AB	.68 ^{os}	.53 ^{oo}	.85 ^{ss}	.75 ^{so}	.58 ^{os}	.55 ^{oo}	.63 ^{ss}	.58 ^{so}	.641
4. BC, AB, CD	.55 ^{so}	.88 ^{ss}	.53 ^{oo}	.55 ^{os}	.58 ^{so}	.78 ^{ss}	.53 ^{oo}	.50 ^{os}	.609
5. AB, CD, BC	.38	.55	.58	.50	.33	.53	.58	.45	.484
6. CD, AB, BC	.55	.45	.38	.35	.65	.55	.40	.40	.466
Overall Mean	.60	.63	.60	.59	.57	.58	.54	.54	

Note—The superscript entries indicate the grammatical status of the new element introduced in the second and third sentences as follows: ss, subject-subject; oo, object-object; so, subject-object; os, object-subject. The first letter refers to the second sentence and the second letter to the third sentence.

*For purposes of illustration, the correct array is always ABCD. The entry AB means either The A is to the left of the B or The B is to the right of the A.

The second experiment also demonstrated the importance of the grammatical role of new elements in the second and third sentences. The fact that subjects' errors could be traced to sentences that introduced new elements as grammatical objects is consistent with Huttenlocher's (1968) theory of reasoning strategies used in constructing three-term series. We recognize that with suitable emendations, Clark's (1969) theory may make similar predictions regarding what we have called the grammatical status hypothesis; however, in its present form, Clark's theory does not seem suited to explaining the constructive memory task (cf. Barclay, 1973; Huttenlocher & Higgins, 1971). It should be noted that the relative size of the presentation order effect was somewhat greater than that of the grammatical status effect. In Experiment II, the effect of no matching elements in the second sentence accounted for 37% of the total variance due to treatments whereas the effect of the grammatical status of new elements accounted for only 17% of the total treatment variance. However, with only 54% of the treatment variance accounted for in Experiment II, much more empirical and theoretical work remains to be done.

The results provide very little encouragement for either the correspondence hypothesis or the end anchor hypothesis. As a general observation, it should be noted that most of the unexplained variance in the second

experiment appears to be due to the interaction of presentation order and adjective combinations. Future theoretical efforts, including attempts to resuscitate these two hypotheses, might profitably be directed toward explaining the balance of the interaction variance.

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(Received December 13, 1974.
Revision received March 3, 1975.)