The Psychological Record, 2012, 62, 279–294

MEASURING JOINT STIMULUS CONTROL BY COMPLEX GRAPH/DESCRIPTION CORRESPONDENCES

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Joint stimulus control occurs when responding is determined by the correspondence of elements of a complex sample and a complex comparison stimulus. In academic settings, joint stimulus control of behavior would be evidenced by the selection of an accurate description of a complex graph in which each element of a graph corresponded to particular sentences and phrases in the description. The current research describes a test that detected various degrees of joint stimulus control by different combinations of elements, ranging from complete joint control by all elements to a lack of joint control by any elements.
Key words: joint stimulus control, complex sample stimuli, complex comparison stimuli, college-level content, statistical interaction, graph–text correspondences

In the natural environment, information is frequently presented in the form of stimuli that consist of many elements, or complex stimuli. For instance, a paragraph is a complex stimulus because it consists of numerous elements, such as the words in the paragraph and the letters in each word. Another complex stimulus would be a graph that depicts the interactive effects of two independent variables on a dependent variable and contains many elements, such as the names of the variables and the slope of each function. When a student correctly selects written descriptions that match information presented in graphs, those responses reflect discriminative control by all of the elements of the description, all of the elements of the graph, and the correspondence between the elements of the graph and the elements of the description. This form of discriminative control by corresponding elements of complex stimuli is called *joint stimulus control* (Lowenkron, 1998, 2006). The term is used here as a description but not as an explanation of performance. In everyday language, behavior controlled in this manner reflects "attention" to the description, the graph, and the correspondence between the two. The present research sought to measure joint stimulus control exerted by complex meaningful stimuli.

This research was conducted with support from PSC-CUNY Research Award 61669-00-39 and CUNY Collaborative Research Grant 80209-09-13.

We thank Xiqiang Zhu for his assistance in the development of the software used to conduct the experiment.

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Joint stimulus control is demonstrated when behavior is determined by the correspondence between the elements of two complex and physically dissimilar stimuli. Of necessity, for behavior to be under joint stimulus control, each element of both complex stimuli must exert discriminative control of behavior, which will be referred to as *complex stimulus control*. The results of previous experiments that addressed factors influencing complex stimulus control informed the design of the measurement procedure used to track joint stimulus control in the present experiment. Thus, some representative findings about complex stimulus control are reviewed to provide a context for the measurement of joint stimulus control.

Control by Elements of Complex Stimuli in Simple Discriminations

Reynolds (1961) investigated the acquisition of stimulus control by complex stimuli that consisted of two elements. A triangle on a red background served as S^D, and a circle on a green background served as S^Δ. After discrimination training, the S^D evoked higher rates than did the S^Δ. Each element of both the S^D and the S^Δ was then presented individually under extinction conditions. Different elements of the S^D acquired control over key pecking for each subject. Discrimination training, then, did not result in equal acquisition of control by the elements of the complex stimuli. Johnson and Cumming (1968) investigated the effect of prior exposure to an element of a complex S^D on the control acquired by both elements of that S^D. Their experiment began with discrimination training in which the S^D and the S^Δ were single-element stimuli. Once established, each element was embedded in a two-element complex S^D or S^Δ and discrimination training was repeated with these complex stimuli. During test blocks, the elements of the complex S^D and S^Δ were presented individually and under extinction, and a greater percentage of total responding was evoked by the single stimulus that had acquired control over responding prior to complex stimulus discrimination training. The newer element did not acquire the same degree of control, despite its inclusion as a member of the S^D during complex stimulus discrimination training, a result that is consistent with stimulus blocking (Kamin, 1968). The effect of prior exposure to both elements of complex stimuli was investigated by Emurian and Weiss (1972), who trained each of the two elements of a complex stimulus alone before presenting them together. Their simultaneous presentation occasioned higher response rates than did presentation of either stimulus alone; thus, both elements presented together exerted a greater degree of control than did either element alone.

Control by Elements of Complex Stimuli in Conditional Discriminations

The control of behavior by complex stimuli can also be explored in the context of conditional discriminations. Using a delayed matching-to-sample paradigm (DMTS), Stromer, McIlvane, Dube, and Mackay (1993) explored the degree of discriminative control exerted by sample stimuli that consisted of either one or two elements. During test trials, in which a two-element sample stimulus was presented with two single-element comparisons, the degree of control exerted by the samples was an inverse function of the number of elements included in those stimuli. When control by both elements of complex samples was required, the degree of control exerted by either element was decreased. Critchfield and Perone (1993) employed samples that consisted of one to three shapes presented in a rectangular 3×6 matrix. Each matrix served as a single sample stimulus. If more than one element was in a matrix, the matrix was considered to be a complex stimulus. During testing, increases in the number of shapes presented as elements of the sample stimuli resulted in a decrement in the frequency of selecting the positive comparison stimulus; that is, the degree of control exerted by the sample stimuli was an inverse function of their complexity (the number of elements of which they were constructed).

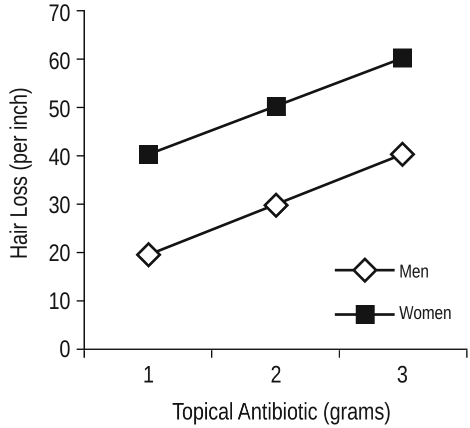
The previous experiments used direct training to establish stimulus control by all of the elements of complex stimuli. In contrast, Markham and Dougher (1993) explored the emergence of control by the elements of complex samples in arbitrary conditional discriminations. Conditional discriminations were established between two-element samples and single-element comparisons (AB–C) and single-element conditional discriminations (C–D). Most participants showed the emergence of symmetrical relations between the unitary samples and the trained comparisons (C–AB), and all showed the emergence of transitive relations between the unitary sample stimuli and the nodally linked comparison (AB–D). Some participants also showed the emergence of equivalence relations among each of the elements of the unitary sample stimuli and the comparison stimuli (D–A and D–B). Therefore, training with complex sample stimuli induced conditional relations between the elements of the sample and other stimuli in the set of trained conditional discriminations. Similar results were obtained with children by Carpentier, Smeets, and Barnes-Holmes (2000). Other studies, however, did not find the emergence of complex stimulus control of behavior (Alonso-Alvarez & Perez-Gonzalez, 2006). Thus, further research is needed to identify the conditions that are sufficient to induce the reliable emergence of complex stimulus control by the elements of stimuli used in conditional discrimination training.

Joint Stimulus Control

The research just described identified some variables that influenced the acquisition and/or emergence of complex stimulus control in the context of simple or conditional discrimination paradigms. These studies, however, did not require responding that was dependent on the correspondence of elements in complex sample stimuli and complex comparison stimuli. Behavior controlled by these sorts of correspondences abounds in the subject matter taught in academic settings (Fields et al., 2009; Fienup, Covey, & Critchfield, 2010). One example would be graphs that convey the interactive effects of two independent variables and written descriptions that describe those effects. One such example involves data that depict the effects of at least two independent variables (IV1 and IV2) on some dependent variable. Frequently, one independent variable changes the effect of another independent variable on the dependent variable, which is referred to as an interaction, and these statistical interactions often are portrayed with graphs. Understanding of an interaction could be said to occur when a student selects a written description of a graph that accurately describes the information portrayed in the graph.

Selection of correct descriptions would thus require control by all the elements of the graphs presented as sample stimuli and all elements of the textual descriptions presented as comparison stimuli. Additionally, selection of the correct comparison would also require control by the relationship between the graph and the textual description; specifically, the textual description must accurately describe the information shown by the graph. Thus, selection of a correct written description would be under the joint control of the elements of both the sample and the comparison stimuli (Lowenkron, 1998, 2006). The aim of the current research was to develop a device to assess such joint control by various elements of complex stimuli, specifically, graphs that portray statistical interactions.

Such an interaction is illustrated by the graph presented in Figure 1, which depicts the effect of gender and antibiotic dosage level on hair loss. The graph depicts (a) the relation between the two independent variables (REL); (b) the name of the independent variable on the abscissa (Independent Variable 1, or IV1); (c) the name of the second independent variable, which is indicated in the legend of the figure (Independent Variable 2, or IV2); (d) the directional effect of the first independent variable when the value of IV1 is set at a low level, that is, the function that has a lower *y* intercept (dIVlo); (e) the directional effect of the first independent variable when the value of IV1 is set at a high level, that is, the function that has a higher *y* intercept (dIVhi); and (f) the name of the dependent variable (DV).



Hair loss (**DV**) was a *direct function* (**dIVlo**) of the *dosage of antibiotics* (**IV1**) taken by *men or women* (**IV2**). For each dosage level of antibiotics, hair loss was *greater for women* (**dIVhi**) relative to men. Increasing the dosage of antibiotics produced a *constant difference* (**REL**) in hair loss for women and men. The hair loss functions for men and women did not intersect at any dosage level of antibiotics.

Figure 1. An example of a graph that depicts the effects of two independent variables on a dependent variable, and a description designed to assess control by the relational statement and the first independent variable using a sample depicting a divergent interaction.

Joint control by all six elements of the graphical stimulus would be demonstrated by production or selection of a textual description that includes accurate references to each of these elements. In addition, evocation of these performances by many novel graphs and descriptions would demonstrate generalized control by all elements of depictions of statistical interactions, which would commonly be referred to as an understanding of the interactive effects of variables on some behavior. The present research sought to measure this joint control through the use of graphs and descriptions that depict the interactive effects of two variables.

Measuring Joint Stimulus Control

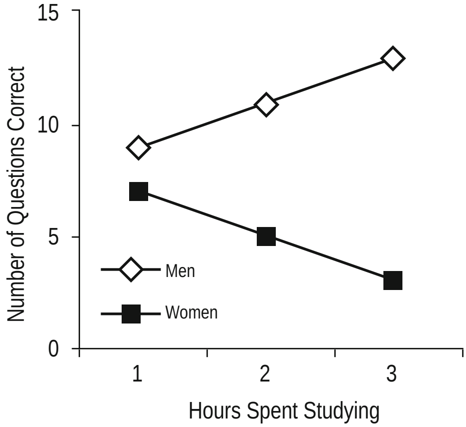
Joint control of responding by all the elements of a graphical sample stimulus can be assessed by the use of trials presented in an arbitrary matching-to-sample format. One approach would involve the presentation of a graph as a sample stimulus with many textual descriptions as comparison stimuli. The correct comparison, also referred to as a positive comparison, or Co+, would be a description of the graph that contained sentences or phrases that accurately and completely denoted all six elements conveyed in the graph. The remaining comparisons would be incorrect and each would be referred to as a negative comparison, or Co−. Each would contain at least one sentence or phrase that was an inaccurate description of one of the six elements of the graph, alone or in combination. Complete joint control would be demonstrated by the selection of the positive comparison instead of any of the negative comparisons.

Because there are six elements in the sample stimulus, a very large number of different negative comparisons can be constructed for a given graph. Some would have only one mistake, others would have up to six mistakes. While it would be theoretically possible to present one test question that included a graph with all of these descriptions, it would be very time consuming for the reader to select the correct description in such a sea of partially correct information. Thus, while theoretically feasible, such an approach is not practical.

A simpler means of assessing joint control by the six elements would involve the presentation of graph-description test questions, each of which would evaluate discriminative control by two elements: the relation between the two independent variables (REL) and one of the remaining elements. Separate questions would be used to evaluate control by (a) the relation between variables (REL) and the name of IV1, (b) the relation between variables (REL) and the name of IV2, (c) the function with the lower *y* intercept (dIVlo), and (d) the function with the higher *y* intercept (dIVhi).

Figure 2 provides one example of this type of test trial in which information is used to evaluate control of behavior by the relation between the independent variables and the name of the Independent Variable 1 (REL & IV1). This test includes the presentation of a graph and three descriptions of the graph. The graph functions as a sample stimulus, while the three descriptions function as comparison stimuli. The correct comparison (Co+) contains an accurate and complete description of the relation between the independent variables and the name of IV1 and is represented symbolically as REL+, IV1+. One incorrect comparison (Co−1) contains an accurate description of the relation between the two independent variables with an incorrect specification of the name of IV1 and is represented symbolically as REL+, IV1−. The other incorrect comparison (Co−2) contains an inaccurate description of the relation between the two independent variables with a correct designation of the name of IV1 and is represented symbolically as REL−, IV1+. Finally, all three comparisons contain accurate descriptions of the remaining elements because control by these elements is not being assessed by the test trials. Thus, they are not represented symbolically in the example. In Figure 2, the code (e.g., REL+, IV1+) and the bold print are for demonstrative purposes. The code indicates the correct and incorrect elements of each answer option, and the incorrect elements within each option are in bold. Neither the code nor the bold text was included in the test proper.

Rel+, IV1− (Co−1)
A) In women, the number of correctly answered questions was a direct function of hours spent studying. In men, the number of correctly answered questions was an inverse function of hours spent studying. For each level of hours spent studying, the number of correctly answered questions was greater for women than for men. Gender reversed the directional effect of the number of hours spent studying on the number of correctly answered questions. As a consequence, each increase in study time produced a growing difference in correctly answered questions. Finally, the number of correctly answered questions for women and men did not intersect at any level of **hours spent exercising**.



Rel−, IV1+ (Co−2)
B) In women, the number of correctly answered questions was a direct function of hours spent studying. In men, the number of correctly answered questions was an inverse function of hours spent studying. For each level of hours spent studying, the number of correctly answered questions was greater for women than for men. Gender **did not influence** the effect of the number of hours spent studying on the number of correctly answered questions. Finally, the number of correctly answered questions for women and men did not intersect at any level of hours spent studying.

Rel+, IV1+ (Co+)
C) In women, the number of correctly answered questions was a direct function of hours spent studying. In men, the number of correctly answered questions was an inverse function of hours spent studying. For each level of hours spent studying, the number of correctly answered questions was greater for women than for men. Gender reversed the directional effect of the number of hours spent studying on the number of correctly answered questions. As a consequence, increases in study time produced a growing difference in correctly answered questions. Finally, the number of correctly answered questions for women and men did not intersect at any level of hours spent studying.

Figure 2. An example of a graph that depicts the effects of two independent variables on a dependent variable, and descriptions designed to assess control by the relational statement and the first independent variable using a sample depicting a divergent interaction.

When a number of trials like these are presented, different patterns of responding to the three comparisons indicate (a) selective discriminative control by the relation between the independent variables in combination with the name of IV1, (b) selective discriminative control by the relation but not by the name of IV1, or (c) control by the name of IV1. Patterns of responding indicative of each form of discriminative control are shown in the rows of Table 1, where the cellular entries indicate the likelihood of selecting each of the three comparisons when these trials are presented a number of times. The form of control is determined via the application of a discrimination analysis to the three answer options, as outlined in each of the next three sections.

REL and IV1

The outcome depicted in Row 1 of Table 1 involves the selection of Co+ only, with no selection of Co−1 or Co−2, and is represented as 100-0-0. The Co+ contains correct information about the relation between the two independent variables and the correct name of IV1 (REL+ & IV1+). Each Co− contains accurate information about one of these elements but not the other. Co−1 contains an accurate statement of the relation between the independent variables and an incorrect name for IV1 (REL+ & IV1−). Co−2 contains an inaccurate statement of the relation between the independent variables and the accurate name for IV1 (REL− & IV1+). When considering the presence of correct statements of the relation and the name of IV1, the Co+ functions as an S^D for the presence of both elements, while both the Co−1 and the Co−2 function as S^s, as they are missing an accurate statement of one of these elements. The uniform selection of Co+, then, would demonstrate control of comparison selection by the relational statement in combination with the name of the first independent variable.

Table 1
Pattern of Comparison Selection That Indicates Control by the REL and IV1

Source of control	Co+ (REL+, IV+) + +	Co−1 (REL+, IV1−) + −	Co−2 (REL−, IV1+) − +
REL and IV1	100	0	0
REL only	50	50	0
IV1 only	50	0	50

Note. The + and − below each Co indicate the status of the relational statement and the name of IV1, respectively. The numerical values in the cells of the table indicate the percentages or likelihoods of selecting the comparisons indicated in each column heading.

REL but not IV1

The outcome depicted in Row 2 involves the selection of Co+ and Co−1 with equal probability and no selection of Co−2, and is represented as 50-50-0. The Co+ and Co−1 contain correct information about the relation between the two independent variables. In contrast, Co−2 contains an inaccurate relational statement. With regard to accuracy of the relational statement, Co+ and Co−1 serve as S^Ds, while Co−2 serves as an S^. The selection of the Co+ and Co−1 and the nonselection of the Co−2 would indicate selective discriminative control exerted by the accurate relational statements. In addition, the Co+ and Co−1 are selected with equal probability because both answers contain accurate relational statements, which are controlling comparison selection. Finally, the accurate name of IV1 is present in Co+ and absent in Co−1. Because both of these stimuli are selected with equal likelihood, the performances are uncorrelated with the presence of the accurate name of IV1. Therefore, selection could not be under the control of the name of IV1.

IV1 but not REL

The outcome depicted in Row 3 involves the selection of Co+ and Co–2 with equal probability and no selection of Co−1, and is represented as 50-0-50. The Co+ and Co–2 contain the correct name of IV1. In contrast, Co–1 contains an inaccurate name of IV1. When accuracy of IV1 naming is considered, Co+ and Co–2 serve as S^Ds, while Co–1 serves as an S^. The selection of the Co+ and Co–2 and the nonselection of the Co–1 thus demonstrate selective discriminative control evoked by the accurate name of IV1. In addition, the Co+ and Co–2 are selected with equal probability because both answers contain accurate names of IV1, which is exerting discriminative control over responding. Finally, an accurate relational statement is present in Co+ and absent in Co–2. Because both of these stimuli are selected, the performances are uncorrelated with the accuracy of the relational statements. Therefore, the relational statements could not be controlling responding.

Assessing Control by all Elements of a Graph

A comprehensive measure of control by all elements included in a graph can be obtained by conducting tests for the relation and each of the other elements: REL and IV1, REL and IV2, REL and dIVlo, REL and dIVhi, and REL and DV. Taken together, the test performances would indicate which elements of the graph, combined with the relational statements, are controlling the selection of the textual descriptions of the graphs.

Four different outcomes are illustrated in Table 2. In the top section, each type of test produces a 100-0-0 pattern of responding. The consistent selection of the positive comparisons in all of the tests indicates control by all six elements in combination with the relations between the two independent variables. Such an outcome indicates control by relational statements in combination with the first and second independent variables and the different directional effects of IV1.

Table 2
Different Patterns of Control Exerted by Elements and Relations Between Independent Variables

Test type	Co+ (REL, Other) + +	Co–1 (REL, Other) + –	Co–2 (REL, Other) – +
Control by all elements in combination with the relation between independent variables			
REL and IV1	100	0	0
REL and IV2	100	0	0
REL and dIVlo	100	0	0
REL and dIVhi	100	0	0
Control by the relation between the independent variables but not other elements			
REL and IV1	50	50	0
REL and IV2	50	50	0
REL and dIVlo	50	50	0
REL and dIVhi	50	50	0
Control by all elements but not the relation between the independent variables			
REL and IV1	50	0	50
REL and IV2	50	0	50
REL and dIVlo	50	0	50
REL and dIVhi	50	0	50
Differential control by the relation between independent variables and other elements			
REL and IV1	100	0	0
REL and IV2	100	0	0
REL and dIVlo	50	50	0
REL and dIVhi	50	0	50

Note. Numbers in cells indicate percentages or likelihoods of selecting the comparison stimulus at the head of each column.

In the second section of Table 2, each type of test produces a 50-50-0 pattern of responding. The consistent selection of Co+ and Co–1 and the nonselection of Co–2 indicate control by the relational statement only and none of the other variables.

In the third section of Table 2, each type of test produces a 50-0-50 pattern of responding. The consistent selection of Co+ and Co–2 and the nonselection of Co–1 indicate control by all the nonrelational elements and no attention to the relational statements.

Finally, the bottom section of Table 2 indicates a complex pattern of responding that indicates control by some elements of a graph and not others. In this example, responding is under the control of the relation between the independent variables in combination with the names of both independent variables, but not in combination with dIVlo. Finally, control by the relation does not occur in combination with dIVhi.

To summarize, control by the elements depicted in a graph that shows the effects of two independent variables on some behavior can be analyzed using the procedures described herein. To date, this type of analysis has not been used to assess control by the many elements that are imbedded in graphs such as these. The present experiment consisted of the presentation of 16 questions like those described previously. They were divided into groups of four. All of the questions in a group assessed control by the relational statement in combination with the same element. One group of four assessed control by REL and IV1, another by REL and IV2, another by REL and dIVlo, and another by REL and dIVhi. The goal of the present experiment was to measure joint control by each of these five elements of graphs and written descriptions of graphs, or five-element joint stimulus control.

Method

Participants

The participants were 20 undergraduate students enrolled in introductory psychology courses at Queens College/CUNY, who received course credit for participating in the experiment. This pool of participants was selected for study because we assumed a wide range of knowledge regarding statistical interactions, but no information was gathered regarding that knowledge prior to participation in the study.

Apparatus

Setting, hardware, and software. Computer-based tests were administered in the Human Learning Laboratory at Queens College/CUNY. Participants were seated individually in cubicles that contained an IBM computer, a keyboard, a desk, and a chair. All stimuli were presented on a 380-mm SVGA computer monitor, and all responses involved pressing specific keys on the keyboard. A customized computer program controlled all aspects of testing, including presentation of stimuli and recording of participant responses.

Stimuli. The test in this procedure contained 16 questions, each of which contained a graph and three descriptions of the graph. The graphs and textual descriptions were of four different types of statistical interaction, as discussed previously and illustrated in Table 3. Each graph depicted the effects of two independent variables on some behavior. Different graphs depicted (a) no interaction or additivity, (b) crossover or antagonistic interactions, (c) synergistic interactions, or (d) divergent interactions. Four graphs were used to depict each type of interaction, resulting in 16 graphs. The graphs that depicted no interaction had two functions with the same slopes but different intercepts. The graphs that depicted crossover interactions had two functions with opposing slopes that also intersected at some intermediate value of one of the independent variables. The graphs that depicted divergent interactions had functions that had opposing slopes and that did not intersect. Finally, the graphs that depicted synergistic interactions had two functions with slopes that were either positive or negative but were different and did not intersect.

Each graph was presented with three descriptions that were designed to assess control by the relational statement in combination with one of the four other elements described previously. The Co+ description, which was designated as REL+ and OTHER+, contained text that accurately described the relation between the effects of the two variables (REL+) and an accurate description of one of the other variables (e.g., IV1+). The Co–1 description, which was designated as REL+ and OTHER–, contained text that accurately described the relation between the effects of the two variables (REL+) and an inaccurate description of one of the other variables (e.g., IV1–). The Co–2 description, which was designated as REL– and OTHER+, contained text that inaccurately described the relation between the effects of the two variables (REL–) and an accurate description of one of the other variables (e.g., IV1+). Thus, four questions assessed control by the relational statement in combination with each of the four elements, and each interaction class was depicted in four sample graphs.

Table 3
Questions Representing the Four Types of Interactions (Columns) That Were Used to Assess Control by the Relational Term and One Other Element, Each of Which Is Indicated in a Separate Row

	Type of interaction			
Trial types	None	Crossover	Divergent	Synergistic
REL & IV1	1	2	3	4
REL & dIVlo	5	6	7	8
REL & IV2	9	10	11	12
REL & dIVhi	13	14	15	16

Note. The numbers in the cells refer to each unique combination of interaction and independent variable used in combination with the relational statement. For example, Question 1 evaluated control by the relational statement in combination with IV1 for a no-interaction graph. Questions 5, 6, 7, and 8 evaluated control by relational statements in combination with dIVlo. Questions 3, 7, 11, and 15 evaluated four forms of joint control for graphs that depicted divergent interactions.

Procedure

Preliminary instructions. Before participants began the computer-based test, the following instructions appeared on the screen: “In this experiment, you will be presented with graphs and descriptions. A graph will appear on the left side of the screen, and three descriptions will appear on the right. Press the key that corresponds to the description that best matches the graph, either A, B, or C. Call the experimenter if you have any questions. If not, press ‘Enter’ to continue.”

Test administration. The test was administered using a computer-based test that contained the previously mentioned 16 questions presented in a random sequence that was controlled by the computer software. Each participant was seated in an experimental cubicle and given the computer-based test. The participants were told to read and follow the instructions on the computer screen. If a participant did not complete the test within 60 min, he or she was dismissed from the experiment.

Results

Test Duration

Participants required an average of 30 min to complete the test. There was, however, a substantial variation of that time, which ranged from 15 to 50 min across participants.

Level of Joint Stimulus Control

The data for all participants were analyzed in terms of the procedures described previously and are shown in Figure 3. Each matrix displays the results for an individual participant. Each row in a matrix represents results of four test trials, each of which involved the presentation of one of the four relational statements in combination with the nonrelational element listed in the far-left column in the row. Joint stimulus control by the relations in combination with the indicated element was demonstrated by the selection of the Co+ on at least three of the four questions. With three comparisons per trial, the chance probability of selecting the correct comparisons in at least three of the four trials is less than .036 (.33 × .33 × .33). Using this criterion for joint stimulus control, each row in the matrix then measures joint stimulus control by the four interactions in combination with a single nonrelational element. The four rows of the matrix, then, can measure from zero to four levels of joint stimulus control. A high level of joint control was defined as the selection of the descriptions that contained the relational statements in combination with at least three of the four nonrelational elements. An intermediate level of joint control was defined as selection of the descriptions that contained the relational statements in combination with two of the four nonrelational elements. Finally, a low level of joint control was defined as selection of the descriptions that contained the relational statements in combination with no more than one of the four nonrelational elements.

Eight participants demonstrated a high level of joint stimulus control, four participants demonstrated an intermediate level of joint stimulus control, and the remaining eight demonstrated a low level of joint stimulus control. Thus, the results show a bimodal distribution of participant performances with regard to level of joint control.

Control by Specific Relations and Elements

The analysis in the previous section focused on variations in frequencies of occurrence of joint stimulus control. For each row in a matrix, there are many different patterns of comparison selection that could occur across the presentation of the relations in combination with a nonrelational element. Many of these patterns are representative of different patterns of stimulus control.

As mentioned, a high level of joint control by the relational statements and the element is indicated by one of three outcomes: 4-0-0, 3-0-1, or 3-1-0 (each indicated by a gray row in the matrices). The 4-0-0 outcome indicates selection of the Co+s only. This pattern of responding occurred a total of 21 times, on 26% of the test trials. The 3-0-1 and 3-1-0 outcomes both indicate selections of the Co+ on three of the four questions and selection of one Co– on one of the four questions. These two patterns occurred on 20 tests, or on 25% of the test trials. In all three of these patterns, participants selected the Co+ on at least three of the four questions of a given type.

Other numerical combinations indicate differential control by the relational statements in combination with the other elements. A 2-0-2 combination (designated by “A” in Figure 3) indicates equally frequent selection of the Co+s and Co–2s, each of which contains a correct element and an incorrect relational statement. Therefore, the 2-0-2 combination documented control by the element and not the relational statement. This form of stimulus control occurred on eight tests, or on 10% of trials, once each for six participants and twice for one participant.

A 2-2-0 combination (designated by “B” in Figure 3) indicates equally frequent selection of the Co+s, which contain a correct relational statement and a correct element, and the Co−1s, which contain a correct relational statement and an incorrect element, and nonselection of the Co−2, which contains a correct element and an incorrect relational statement. Thus, the 2-2-0 combination indicated control by the relational statement and a lack of control by the element. This form of stimulus control occurred on three tests, or on 4% of trials, once each for three participants.

Elements Controlling Selection

4

tf3726	Co+	Co-1	Co-2
IV1	4	0	0
IV2	4	0	0
dIVlo	4	0	0
dIVhi	3	0	1

tf3734	Co+	Co-1	Co-2
IV1	4	0	0
IV2	4	0	0
dIVlo	3	0	1
dIVhi	3	0	0

tf3743	Co+	Co-1	Co-2
IV1	3	1	0
IV2	4	0	0
dIVlo	4	0	0
dIVhi	3	1	0

tf3742	Co+	Co-1	Co-2
IV1	3	1	0
IV2	4	0	0
dIVlo	4	0	0
dIVhi	4	0	0

tf3735	Co+	Co-1	Co-2
IV1	3	1	0
IV2	3	1	0
dIVlo	4	0	0
dIVhi	4	0	0

3

tf3746	Co+	Co-1	Co-2	
IV1	1	3	0	D
IV2	4	0	0	
dIVlo	4	0	0	
dIVhi	4	0	0	

tf3740	Co+	Co-1	Co-2
IV1	2	1	1
IV2	3	0	1
dIVlo	3	1	0
dIVhi	4	0	0

tf3733	Co+	Co-1	Co-2	
IV1	0	2	2	E
IV2	3	0	1	
dIVlo	3	0	1	
dIVhi	3	0	1	

2

tf3730	Co+	Co-1	Co-2	
IV1	0	1	3	C
IV2	2	0	2	A
dIVlo	3	1	0	
dIVhi	4	0	0	

tf3739	Co+	Co-1	Co-2
IV1	1	1	2
IV2	2	1	1
dIVlo	4	0	0
dIVhi	3	1	0

tf3738	Co+	Co-1	Co-2	
IV1	2	2	0	B
IV2	4	0	0	
dIVlo	4	0	0	
dIVhi	2	1	1	

tf3747	Co+	Co-1	Co-2	
IV1	0	3	1	D
IV2	3	1	0	
dIVlo	3	1	0	
dIVhi	2	0	2	A

1

tf3744	Co+	Co-1	Co-2	
IV1	2	1	1	
IV2	2	0	2	A
dIVlo	1	1	2	
dIVhi	3	1	0	

tf3728	Co+	Co-1	Co-2	
IV1	2	1	1	
IV2	0	2	2	E
dIVlo	1	2	1	
dIVhi	3	0	1	

tf3741	Co+	Co-1	Co-2	
IV1	2	2	0	B
IV2	2	0	2	A
dIVlo	3	0	1	
dIVhi	2	0	2	A

tf3745	Co+	Co-1	Co-2	
IV1	1	1	2	
IV2	4	0	0	
dIVlo	1	2	1	
dIVhi	2	0	2	A

tf3729	Co+	Co-1	Co-2	
IV1	0	3	1	D
IV2	3	0	1	
dIVlo	1	1	2	
dIVhi	2	1	1	

0

tf3737	Co+	Co-1	Co-2	
IV1	1	3	0	D
IV2	2	2	0	B
dIVlo	1	0	3	C
dIVhi	2	0	2	A

tf3727	Co+	Co-1	Co-2	
IV1	1	1	2	
IV2	2	1	1	
dIVlo	2	1	1	
dIVhi	2	0	2	A

tf3736	Co+	Co-1	Co-2	
IV1	1	0	3	C
IV2	2	1	1	
dIVlo	1	2	1	
dIVhi	0	1	3	C

Legend

A	2	0	2
B	2	2	0
C	x	x	3
D	x	3	x
E	0	2	2

Figure 3. The results of the joint stimulus control test. Each matrix contains data for an individual participant.

Other tests evoked the selection of one of the Co−s on three of the trials in a test. These combinations can be grouped based upon the selection of Co−1 or Co−2. The 0-1-3 and 1-0-3 combinations (designated by “C” in Figure 3) indicate selection of the Co−2, which contains an incorrect relational statement along with a correct description of the element. These combinations thus suggest control by the combination of an incorrect relational statement and a correct description of the element. These combinations occurred four times, or on 5% of trials, once each for two participants and twice for one participant.

The 0-3-1 and 1-3-0 combinations (designated by “D” in Figure 3) indicate selection of the Co−1, which contains an incorrect element, along with a correct relational statement. These combinations thus suggest control by the combination of a correct relational statement and an incorrect description of the element. These combinations occurred four times, once each for four participants. The remaining test outcomes, 0-2-2 (designated by “E”), 2-1-1, 1-1-2, and 1-2-1, are not readily interpretable and might indicate random comparison selection. These outcomes occurred 19 times, or on 24% of trials, once each for three participants, twice each for five participants, and three times each for two participants.

Joint Control and Type of Interaction

The data in Figure 3 were aggregated across types of interactions. The data for each participant can also be analyzed to determine the level of joint control occasioned for each type of interaction, as shown in Table 4. Each row displays the data for an individual participant. Each column contains the data for one type of interaction. The number displayed in each cell indicates the number of trials of a given interaction type on which combined control was demonstrated, the maximum being four trials. Any cellular entry of 3 or 4 indicates joint control for that type of interaction because the participant selected an answer that indicated control by the relational statement and at least three of the four nonrelational elements. A comparison across types of interactions, then, would indicate the prevalence of joint stimulus control across different types of interactions.

Variation across participants can be seen by a comparison of entries in different rows. For example, Participant 3734 demonstrated a high level of joint control for all four types of interaction. The performance of Participant 3736 indicated a generally low level of joint stimulus control regardless of type of interaction. The performance of Participant 3744 indicated high levels of joint control for crossover and divergent interactions and low levels of joint control for no interaction and synergistic interaction. Finally, the performance of Participant 3737 indicated a high level of joint control for graphs that depicted crossover interactions only and not by the other types of interactions.

The information in the bottom row of Table 4 indicates the prevalence of high levels of joint control by each type of interaction for the group of participants in the study. The values in these cells indicate the percentage of participants who demonstrated a high level of joint control on trials of a given interaction type, defined as responding accurately on at least three of four such trials. High levels of joint control on trials with content indicative of no interactions and synergistic interactions were exhibited by modest and similar percentages of participants, while high levels of joint control on trials indicative of crossover and divergent interactions were exhibited by a relatively high percentage of participants.

Discussion

Students frequently do not select accurate and complete textual descriptions of complex graphs. This “difficulty” could reflect inattention to or absence of discriminative control by the elements of the graphs, the information in the written descriptions of the graphs, or the correspondence between both sets of elements, the latter of which is referred to as joint stimulus control. The present experiment described a method that measured the degree and type of joint control among these variables. Of the college undergraduates who participated in this study, 40% demonstrated a high level of joint control, 20% demonstrated an intermediate level of joint control, and the remaining 40% demonstrated a low level of joint control. On a group level, the tests documented a bimodal distribution of students who showed control by the correspondence of the elements in interaction-based graphs and textual descriptions of that visually presented information, highlighting the difficulty related to joint stimulus control.

Table 4
The Number of Correctly Answered Questions of Each Type of Interaction

	Type of interaction			
Participants	None	Crossover	Divergent	Synergistic
3734	3	4	4	4
3742	4	4	4	3
3726	4	4	4	3
3743	4	3	3	4
3735	3	4	3	4
3746	3	3	4	3
3738	3	3	3	3
3740	4	3	3	2
3739	2	2	4	2
3730	2	2	3	2
3727	1	3	3	2
3733	1	3	2	3
3741	1	3	3	2
3747	3	1	3	1
3745	1	3	2	2
3744	0	4	3	1
3729	1	2	2	1
3728	1	2	2	1
3737	2	3	1	0
3736	2	1	1	0
% participants with 3 or 4 correct	45	70	70	40

Note. Each row shows the data for an individual subject. Each column indicates the type of interaction.

On a within-student basis, the test performances identified specific forms of joint stimulus control that determined student behavior. Some participants demonstrated complete joint control by the relational statements in combination with all four of the other elements in the graphs and descriptions (4-0-0s, 3-0-1s, and 3-1-0s), others showed control by the relational statements and some, or none, of the other elements, and yet others showed control by the nonrelational elements in a graph but not to the relational effects of the two independent variables. Thus, specific areas of difficulty were identified by performances engendered by the testing procedure and were characterized in terms of the stimulus control topographies that controlled behavior.

In some cases, the tests also documented joint control occasioned by particular types of interaction. When a participant selected the correct comparisons on at least three of the four questions for a given type of interaction, joint control was documented for that sort of interaction. In contrast, when performance levels were lower, it was not possible to determine whether joint control was exerted by a given type of interaction because the test contained two few trials with a given type of interaction. This problem could be solved by increasing the number of trials that contain examples of a given type of interaction. Additional research will be required to determine whether similar outcomes to those in the current study would be obtained with stimuli drawn from other content areas.

Alternative Metrics of Joint Stimulus Control

The mode of analysis used in the present study identified various degrees of joint stimulus control as exerted by various combinations of types of interactions with various nonrelational elements. An alternative way of measuring complete joint stimulus control would involve computing accuracy based on the responses evoked by all 16 questions. For example, complete joint stimulus control could be defined by the occurrence of at least 14 of 16 correct answers, as long as no row contained more than one error. In that case, five of the 20 participants showed complete joint stimulus control, while the remaining 15 participants did not. We are of the opinion that such a molar and binary approach is too restrictive and is not sensitive to the identification of restricted aspects of joint stimulus control, which is accomplished by the approach used to analyze the data in the present study.

The testing procedure described in the present study identified various degrees of joint stimulus control along with simpler forms of stimulus control. Given a general absence of joint stimulus control, such a generalized repertoire might be induced by the use of matrix training and testing (Goldstein, 1983, 1985; Goldstein & Mousetis, 1989). Specifically, training could be conducted with one relational statement and one element for each type of interaction and the establishment of the generalized joint control repertories (e.g., the combinations designated by cells 1, 6, 11, and 16 in Table 3.) The induction of a generalized joint stimulus control repertoire could then be evaluated with the presentation of test questions drawn from information contained in the remaining cells in the table, each of which would involve untrained combinations of a relational statement and another element in the context of a novel exemplar of a type of interaction graph. Accurate performances occasioned by trials corresponding to the combinations designated by cells 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, and 15 would document the emergence of a generalized joint stimulus control repertoire across graphs that represent four types of interactions.

Theoretically, other test results could identify specific deficits in joint control. That information could be used diagnostically to inform the preparation of a training intervention designed to establish only the missing forms of joint stimulus control. If successful, this approach would minimize the training needed to induce a generalized joint stimulus control repertoire that would enable an individual to identify the correspondences of the elements shown in graphs of different sorts of interactions and select the written descriptions of those graphs.

To conclude, many situations require an individual to attend to complex events and describe them or select accurate and complete descriptions of the events. When that occurs, the performances are controlled by point-to-point correspondences between elements of complex stimuli and elements in complex descriptions. This control by correspondences is called joint stimulus control. The measurement of joint stimulus control in the present study was illustrated with graph–text correspondences drawn from the domain of statistics or experimental design. This mode of analysis, however, is not restricted to content in this quantitative realm. Indeed, the mode of evaluating joint stimulus control described herein could also be used with content in other academic areas such as art history. In this case, joint stimulus control would be manifested when a student selects full and accurate descriptions of paintings or sculptures. Thus, the study of joint stimulus control should be relatively content independent. The validity of this surmise, however, will await additional research.

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