Journal of Experimental Psychology:
Learning, Memory, and Cognition
1998, Vol. 24, No. 6, 1437–1458

0278-7393/98/$3.00

Two Competing Attentional Mechanisms in Category Learning

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This research provides evidence that there are 2 competing attentional mechanisms in category learning. Attentional persistence directs attention to attributes previously found to be predictive, whereas attentional contrast directs attention to attribute values that have not already been associated with a category. Three experiments provided evidence for these mechanisms. Experiments 1 and 2 provided evidence for persistence because increased attention to an attribute followed training in which that attribute was relevant. These experiments also provided evidence for contrast because attention was also increased to the values of an attribute when the values of another, more salient attribute had already been associated with categories. Experiment 3 provided evidence that persistence operates primarily at the level of attributes, whereas contrast operates at the level of attribute values.

Learning theorists have relied on the notion of attention to explain how learning one discrimination can be facilitated or hindered by the prior learning of another discrimination. In particular, learning a discrimination is dependent on attention to the relevant attribute. Two seemingly contradictory mechanisms have been proposed for the changes in attention following a successful discrimination. According to one mechanism, which we call *attentional persistence,* increased attention is allocated to attributes that have been found to be predictive of an outcome. This mechanism is involved in the analyzer theory of Sutherland & Mackintosh (1971). According to the analyzer theory, when a discriminative stimulus in an operant conditioning paradigm is found to be predictive of reinforcement, greater attention is devoted to the relevant attribute of the discriminative stimulus. Because the total pool of attentional resources is fixed, this requires a decrease in attention to other attributes. As a result, a learner is better able to learn a second discrimination involving the same attribute but is less able to learn a discrimination involving a different attribute. Attentional persistence plays a role not only in theories of operant conditioning but also in prominent theories of categorization (e.g., Kruschke, 1992; Nosofsky, 1986).

A second attentional mechanism, which we call *attentional contrast,* works in the opposite direction. In particular, once a value of an attribute has been associated with a category, attention is allocated to other attribute values when another category must be learned. This mechanism is involved in the Pearce–Hall model of learning (Pearce & Hall, 1980). According to this model, stimuli receive attention only to the extent that their consequences are unclear. Thus, once an attribute value has been found to be reliably associated with a given outcome, attention to that attribute value is reduced. This theory thus appears to stand in opposition to the analyzer theory, in which a consistent predictor of an outcome receives greater attention.

Evidence for Attentional Persistence

Early evidence for attentional persistence can be found in the classic study of Lawrence (1949). In the first stage of this study, rats in the experimental condition were placed in a maze with one white arm and one black arm. We refer to such dimensions of variation, regardless of whether they vary quantitatively or qualitatively, as *attributes* (e.g., color). We refer to specific points along these dimensions as *values* (e.g., black). Rats were reinforced for entering the black arm. Attentional persistence would thus predict increased attention to the color attribute following this discrimination. In contrast, rats in a control condition were trained in a gray maze with texture rather than color predicting reinforcement. After this first stage of learning, rats were placed in mazes that had either two white arms or two black arms. Rats were reinforced for entering the right arms of black mazes and the left arms of white mazes. Thus, prior associations learned in the first stage involving specific values of color would not help rats learn these new contingencies. Consistent with attentional persistence, experimental rats learned these contingencies faster than control rats, presumably because of increased attention to color following the first stage of training.

Further evidence for persistence has come from studies of intradimensional versus extradimensional shifts in discrimination. For example, Mackintosh and Little (1969) presented pigeons with pairs of stimuli that varied on both the color and orientation of a stripe. One group of pigeons was reinforced for pecking a stripe of a particular color, whereas a second group was reinforced for pecking a stripe of a particular orientation. Following this initial training, both groups were transferred to a task in which only color was

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We thank Julie Earles for helpful comments on a previous version of this article.

Examples of the events used as stimuli in this research are available over the World Wide Web at http://www.psy.fau.edu/chez/awk/home.html.

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relevant. Two new colors and two new orientations were used so that prior associations would presumably not directly affect pigeons' performance. Pigeons that were subject to an intradimensional shift (i.e., those that were initially trained on color) performed better on this transfer task than did pigeons who were subject to an extradimensional shift. This finding may reflect attentional persistence to the attribute that was relevant in the first stage of learning.

Evidence for persistence in humans has come from a study by Kruschke (1996). Kruschke first trained undergraduate participants on a categorization problem requiring attention to two out of three varying attributes. Some participants were transferred to a categorization problem requiring attention to one of the previously relevant attributes. Others were transferred to a problem requiring attention to the previously irrelevant attribute. Participants who were able to categorize the transfer stimuli on the basis of a previously relevant attribute learned the categorization more quickly than those who had to shift attention to a previously irrelevant attribute. Recent evidence by Macho (1997) has also demonstrated that human participants persist in attending to a previously relevant attribute when a new set of categorization stimuli is presented.

Evidence for Attentional Contrast

Evidence for contrast comes from word-learning biases in children. Children who are presented with a novel category label have been found to attend more to a previously unlabeled object than to an already labeled object (Markman & Wachtel, 1988). Thus, consistent with contrast, children attended more to information that was previously unpredictive of category membership than to information that they had already discovered to be predictive.

Although this effect is often discussed at the level of whole objects, it may be more accurate to characterize it in terms of the values of individual attributes. Children have been found to associate a novel noun primarily with particular attributes of an object such as shape. In particular, when children are presented with a novel word along with a novel object, they generally extend that word to objects with the same shape but not to objects with a different shape (Landau, Smith, & Jones, 1988). For example, a child who has just learned the word *horse* would likely extend the use of that label to similarly shaped animals such as zebras but not to similarly colored animals such as cows. If a novel word is presented along with a shape that already has a label, however, children shift attention to the shapes of other objects that are present. For example, if a child were presented with the word *cow* and the only objects present were a previously labeled horse and an unlabeled cow, the child would be likely to associate the new word with the shape of the cow. If there are no other objects, children shift attention to values of other attributes of an object (Markman & Wachtel, 1988). For example, if a child who had just learned *horse* was presented with the label *zebra* and the only object present was a zebra, that child would be likely to shift attention away from the shape of the object and toward other attributes of the object such as its coloration (i.e., its stripes).

Markman & Wachtel (1988) interpreted these findings as evidence for a mutual exclusivity assumption in children. According to this assumption, an object can have only one label, and thus if no unlabeled objects are present, a novel label must refer to something else. Although mutual exclusivity may reflect a conscious word-learning strategy on the part of children, it may also reflect the operation of a more general attentional mechanism. Research in the animal conditioning literature has revealed results that are quite similar to those in child language learning. For example, in the phenomenon called "latent inhibition," animals have difficulty learning associations involving a stimulus to which they have previously been exposed (Lubow & Moore, 1959). For example, after preexposure to a light, rats have difficulty learning the later predictiveness of the light if both the light and a novel tone predict reward. According to one major account of latent inhibition (Hall, 1991), associations developed by a stimulus during preexposure interere with its ability to enter into subsequent associations. This same mechanism, which is quite consistent with contrast, could also account for a bias to associate novel words with novel referents in children. In particular, once an attribute value has been associated with a category, children may have difficulty learning new associations involving that attribute value.

An additional finding that may reflect contrast has come from Schyns and Rodet (1997). Participants learned two categories of "Martian cells," one defined by a single novel feature (X) and one defined by this feature contiguous with a second novel feature (Y). The X-XY group learned the X category prior to the XY category. This group was predicted to represent the XY category as the conjunction of the X and Y features. In contrast, the XY-X group learned the XY category before the X category. This group was expected to represent the XY category as a single conjoined feature because they had never seen X in isolation before learning the XY category. Participants were tested with stimuli involving the same X and Y features separated in space. The XY-X group tended to categorize these as examples of the X category because the conjoined XY feature was not present but the X feature was present. In contrast, the X-XY group tended to categorize them as XY because both the X and Y features were present.

Schyns and Rodet (1997) interpreted their results as evidence for feature creation. In particular, Schyns and Rodet proposed that the creation of an X feature in the first phase of learning allowed participants in the X-XY condition to extract the X feature in the second phase of learning and thus to create an independent Y feature. Attentional contrast may have worked hand in hand with feature creation, however, to draw attention to the Y feature in this condition. In particular, contrast may have directed attention toward information that was not already associated with the X category when a new category was to be learned, resulting in the creation of a Y feature. As a result of this attention to Y, the presence of the Y feature in the test stimuli may have caused participants to categorize these stimuli as examples

of the XY category. In contrast, participants in the XY-X group may have been unable to attend to the absence of Y in order to distinguish the X category from the previously learned XY category. As a result, these participants were more likely than participants in the other condition to categorize the test stimuli as X, even though Y was in fact present in these stimuli.

The Interaction of Attentional Persistence and Contrast

Findings consistent with contrast have provided evidence that learners direct attention away from information that was previously found to be predictive of category membership, whereas findings consistent with persistence have provided evidence that learners direct attention toward this previously predictive information. The distinction between attributes and attribute values may be important in resolving this apparent inconsistency. Persistence may operate primarily at the level of attributes. For example, in the intradimensional versus extradimensional shift literature, the particular values of the attributes that were represented in the transfer stimuli were all entirely novel. Thus, an attentional mechanism that operated only at the level of values could not account for any differences in transfer between the intradimensional and extradimensional shift conditions. The intradimensional condition, however, had received prior training on the relevant attribute, and this resulted in better transfer performance. Thus, when an attribute was found to be predictive of an outcome, persistence resulted in increased attention to that attribute regardless of the values involved.

Contrast may operate primarily at the level of attribute values. Studies that have provided evidence for contrast have all used transfer stimuli involving values of an attribute that have previously been associated with a category. For example, children's association of a word (e.g., *horse*) with a particular attribute value (e.g., a horse shape) encourages them to focus on different values (e.g., a cow shape) when presented with a novel label (e.g., *cow*). In this example, contrast does not direct attention away from an entire attribute (e.g., shape) but rather from a particular value of that attribute (e.g., a horse shape). Contrast does not require attention to be shifted to another value of the same attribute, however. For example, if no novel shapes are present, contrast results in increased attention to values of other attributes such as the substance (Markman & Wachtel, 1988) or motion (Kersten, Fancher, Remec, & Schaefer, 1997) of an object. Thus, although contrast encourages attention to values that have not already been associated with a category, it is indifferent as to which attributes those values come from.

Persistence may direct attention to an attribute, whereas contrast directs attention away from particular values of that attribute that already have a label. For example, a child who is presented with a novel category label along with a previously labeled shape will be likely to continue to attend to shape if other, unlabeled shapes are present. Smith (1995) has presented evidence that this shape bias is not innate but rather develops with noun-learning experience, consistent with an attentional mechanism such as persistence. Thus, after learning the word *horse,* persistence would direct attention to shape, whereas contrast would direct attention away from horselike shapes. As a result, a child who was then presented with the novel word *cow* along with a cow and a zebra would be likely to associate the word with the shape of the cow rather than with the coloration of the zebra. Only if no unlabeled values of an attribute are present does contrast require attention to be shifted to the values of a different attribute. In situations such as this, attentional persistence and contrast may compete with one another to determine the allocation of attention, with persistence favoring one attribute (e.g., shape) and contrast directing attention to the values of a different attribute (e.g., coloration).

When attentional persistence and contrast are in competition with one another, a key factor in determining which process exerts a stronger influence may be the baseline level of attention paid to each attribute. In a recent extension of his attention learning covering map (ALCOVE) model, Kruschke (1996) has proposed that the prior level of attention to an attribute may influence the degree of changes in attention to that attribute. In particular, attributes that are currently receiving very high levels of attention show smaller changes in attention strength than do attributes that are currently receiving more moderate levels of attention. Thus, an attribute that normally receives a high level of attention may receive little extra attention as a result of either persistence or contrast. For example, after children have learned words for a number of different shapes, they may attend strongly to shape as a result of persistence. Because of this already high level of attention, however, little extra attention will accrue to shape following the learning of each additional word for a shape.

An attribute that normally receives a more moderate level of attention may receive a greater increase in attention as a result of persistence or contrast. Thus, if one attentional process favored a highly attended attribute and the other favored a more moderately attended attribute, the process favoring the more moderately attended attribute would exert a stronger influence. For example, if persistence favored a highly attended attribute such as shape and contrast favored a more moderately attended attribute such as coloration, contrast would exert a larger influence, resulting in a relative increase in attention to coloration and a relative decrease in attention to shape.

The present experiments were designed to examine the influences of persistence and contrast on attention to attributes that varied in baseline salience. Participants learned a discrimination in which the values of either a more or less salient attribute could be used to distinguish between categories. Some participants learned this discrimination at the beginning of the experiment, prior to learning any other discriminations. These participants were expected to attend primarily to the more salient attribute when making this discrimination. Other participants first learned a discrimination in which the same values of only one of these two attributes could be used to distinguish between categories. Thus, persistence would result in increased attention to this attribute in the learning of subsequent discriminations.

Contrast would result in increased attention to the other attribute because the values of this attribute would not yet have been associated with categories.

Because persistence and contrast worked in opposite directions in this design, effects of prior learning would be apparent only if one attentional mechanism had stronger effects than the other. As we discussed previously, the baseline salience of an attribute may be important in determining the degree of change in attention to an attribute. Because persistence and contrast favored attributes that differed in baseline salience, the mechanism that favored the less salient attribute was expected to yield a stronger influence. Persistence was expected to dominate over contrast when the less salient attribute was involved in the initial discrimination, resulting in increased attention to that attribute in subsequent discriminations. Contrast was expected to dominate over persistence when the more salient attribute was involved in the initial discrimination, again resulting in increased attention to the less salient attribute in subsequent discriminations.

Experiment 1

Experiment 1 was designed to examine the effects of attentional persistence and contrast on attention to attributes that varied in baseline salience. The attributes that defined the categories were components of simple animated events. Novel verbs accompanied the events, serving as labels for the event categories. Event categories were chosen for investigating attentional persistence and contrast because different attributes of events show consistent differences in their baseline saliences when they are presented in the context of a verb-learning task (Kersten, 1997, 1998, in press). They were also chosen because the present contrast mechanism may be particularly important in the learning of English verbs (see the General Discussion). We believe that the proposed attentional mechanisms are quite general in nature, however, and would also apply to the learning of object categories.

Two attributes of the events were related to the accompanying verbs. These were the path and manner of motion of one of the characters appearing in each event. These attributes were chosen because people have previously been found to attend more to path than to manner of motion in the context of a verb-learning task (Kersten, 1997). In other words, path has a higher baseline salience than manner of motion. Each verb was always accompanied by a particular value of one or both of these attributes. For example, one verb was always accompanied by a character moving along a path directly toward a second character, whereas another verb was always accompanied by a manner of motion involving zig-zagging to the left and right.

The order of learning different types of verbs was varied to influence the amount of attention allocated to each attribute. To provide a baseline measure of attention to path and manner of motion, one group of participants learned verbs that could be distinguished on the basis of either path or manner of motion before learning any other discriminations. For example, one such verb was always accompanied by both the path and manner of motion described above, whereas a second verb was always accompanied by a different path and manner of motion. Because these verbs were defined by a conjunction of values of path and manner of motion, they are referred to as *conjunctive verbs.* Because path is more salient than manner of motion, participants who learned conjunctive verbs first were expected to attend primarily to path when learning these verbs.

Other participants learned verbs that could only be distinguished on the basis of manner of motion before learning conjunctive verbs that could be distinguished on the basis of path as well as these same values of manner of motion. These participants were predicted to attend more to manner of motion when learning conjunctive verbs than participants who learned conjunctive verbs first. This finding would provide evidence for attentional persistence. Because manner of motion was initially less salient than path, this persistence to manner of motion was expected to overwhelm any contrast effects acting to draw attention to path.

The remaining participants learned verbs that could only be distinguished on the basis of path before learning conjunctive verbs that could be distinguished on the basis of manner of motion as well as these same values of path. These participants were also predicted to attend more to manner of motion when learning conjunctive verbs than participants who learned conjunctive verbs first. This finding would provide evidence for contrast. This effect of contrast on attention to manner of motion was expected to overwhelm any persistence effects acting to draw attention to path. Thus, prior learning of verbs involving either path or manner of motion was expected to result in an increase in attention to manner of motion during subsequent conjunctive learning.

Although the order of learning varied, all participants learned path verbs, manner verbs, and conjunctive verbs. For example, participants who learned conjunctive verbs first subsequently learned path verbs and manner verbs. Thus, at the end of learning, all participants could be tested on their ability to distinguish between these different verb types. A participant's ability to distinguish conjunctive verbs from path verbs provided a measure of attention to manner during conjunctive learning because only manner distinguished these two verb types. A participant's ability to distinguish conjunctive verbs from manner verbs, in turn, provided a measure of attention to path.

Participants who learned conjunctive verbs first were expected to attend primarily to path. As a result, these participants were expected to have difficulty distinguishing conjunctive verbs from path verbs. Participants who learned path or manner verbs first were expected to attend more to manner during subsequent conjunctive learning than participants who learned conjunctive verbs first. Because manner is lower in baseline salience than path, this increase in attention to manner following path or manner learning was expected to result in a more even distribution of attention over path and manner. These participants were thus more likely to notice the relation of conjunctive verbs to both path and manner, allowing them to distinguish conjunctive verbs from path verbs.

Method

Participants

One hundred forty-four undergraduates at Indiana University participated in this experiment in partial fulfillment of course requirements for introductory psychology.

Stimuli

All events. Events were displayed on Macintosh IIsi (Apple Computers, Cupertino, CA) computers using MacroMind Director 3.1 (Macromedia, San Francisco, CA). An example event is depicted in Figure 1. Each event involved two buglike characters. One character, the *agent,* moved throughout the event, while the other, the *patient,* remained motionless. The static appearance of each character varied on three attributes, its head, body, and legs. Each of these attributes had two possible values, chosen randomly from the four values used by Kersten (1998). An agent's motion also varied on three attributes. These were the *path, manner of motion,* and *leg motion* of the agent. The two possible values of each of these attributes are depicted in Figure 2. The only other attribute that varied was the environment in which the events took place, represented by a static line-drawing in an unused corner of the screen. There were two possible environments, chosen randomly from the four environments used previously by Kersten (1998).

Each event began after a black screen faded away to reveal the starting positions of the two characters. The agent started each event at a point randomly chosen from a region near the center of the screen. The patient started each event at a varying distance from the agent along one of eight directions, either north, south, east, west, northeast, northwest, southeast, or southwest. Each event lasted approximately 8 s.

Learning events. There were three phases of learning. Participants learned path verbs in one phase, manner verbs in another, and conjunctive verbs in a third. Two verbs were presented in each phase of learning. Each phase involved between one and three blocks of eight learning events. Each verb was presented on four of the eight events within a block, with the order of presentation determined randomly for each participant. Participants were tested on their learning following each block. They were allowed to move on to the next phase of learning if testing indicated that they had learned the verbs in that phase. Participants were allowed to move on regardless of test performance following three blocks of learning in a given phase.

Table 1 shows a schematic description of the categories in Experiment 1. Each event was labeled by a novel verb appearing in an unused corner of the screen. In the path phase, the two verbs (i.e., *spogging* and *zelling*) were perfectly correlated with the two different paths of the agent. Manner of motion did not vary in this phase, with agents moving smoothly throughout. In the manner phase, the two verbs (i.e., *yimming* and *gupping*) were perfectly correlated with the two different manners of motion of the agent. Path did not vary in this phase, with agents oscillating in place either front and back or left and right to represent their manners of motion. In the conjunctive phase, the two verbs (i.e., *morping* and *wunking*) were perfectly correlated both with the paths and with the manners of motion of the agent. All other attributes varied randomly. This random variation was included to make the task more challenging.

Criterion test trials. Following each block of eight learning events, participants were tested on their knowledge of the two verbs they just saw. This was done to ensure that participants had learned the meanings of those verbs before allowing them to move on to the next phase of the experiment. The amount of difficulty participants experienced when learning a particular discrimination can also be used as a measure of attention to the relevant attribute(s) in that discrimination. There were six test trials following each block of learning events, three testing for knowledge of each verb. The order of presentation of the test trials was determined randomly for each participant. Participants were presented with pairs of events, one after the other, each labeled by the same verb. One event in each pair was consistent with the accompanying verb, whereas the other mismatched the verb on either path (in the path phase), manner of motion (in the manner phase), or both (in the conjunctive phase). The correct event was presented first in half of the trials and second in the other half. The

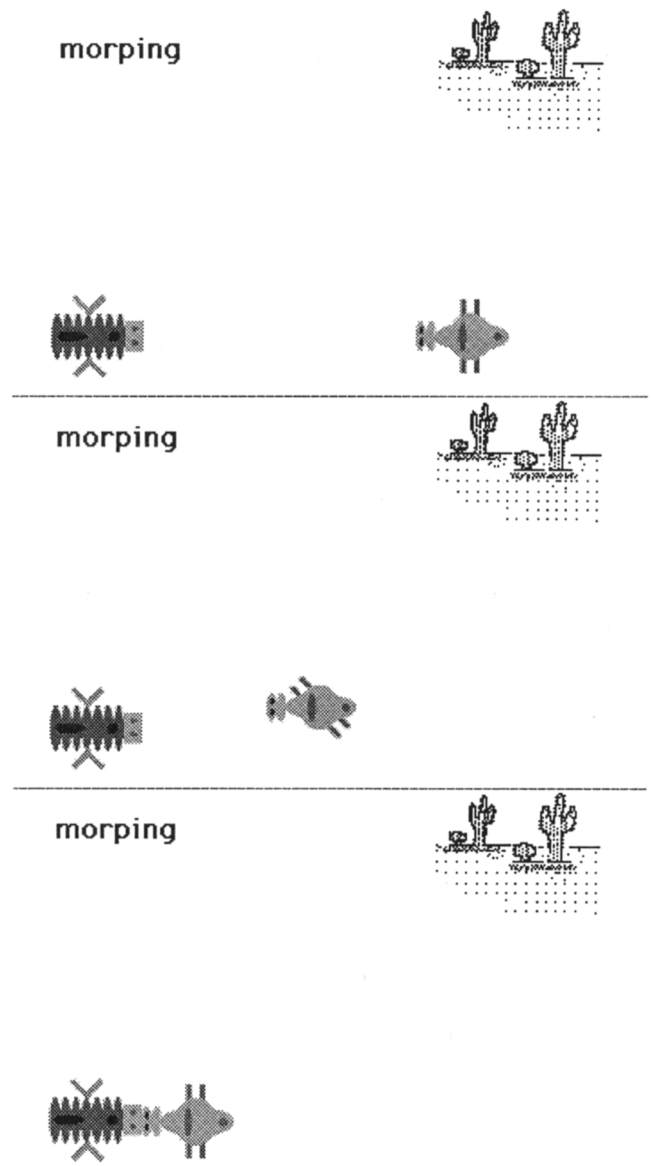

Figure 1. Three frames from an example event in Experiment 1. The agent, on the right, zigzags to its left and right as it moves toward the patient, on the left. The agent's legs move in a rotating motion around its body as it moves. The event is labeled by the verb *morping* and takes place against a desert background.

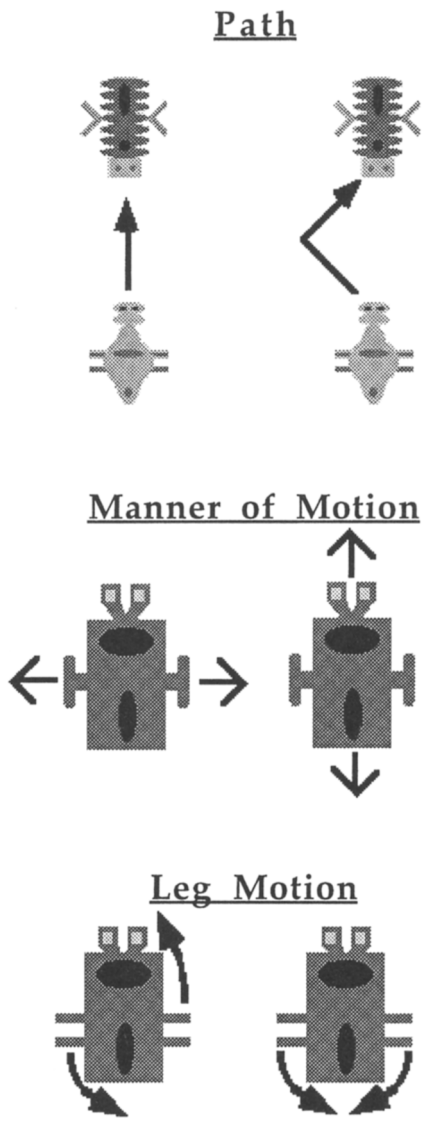

Figure 2. Values of the motion attributes in Experiment 1. One path of the agent involved motion directly toward the patient, whereas the second involved an indirect path to the patient. One manner of motion involved accelerations and decelerations in forward motion (i.e., moving in surges), whereas the second involved leftward and rightward excursions from the agent's path (i.e., zig-zagging). The two leg motions involved rotating motions 45° forward and backward around the body of the agent, either in the same direction by the two legs or in opposite directions.

participant's task was to choose which event was the better example of the accompanying verb. The criterion for moving on to the next phase of the experiment was 100% correct performance on the set of six test trials. Participants were allowed to move on regardless of performance after three blocks in a given phase of learning.

Final test events. Following the third phase of learning, participants were presented with 20 events testing for knowledge of all six verbs seen earlier in the experiment. These final test events were used to determine how well participants could distinguish verbs that were learned in different phases of learning. Recall that conjunctive verbs differed from each of the other two verb types on only one attribute. Thus, a participant's ability to distinguish conjunctive verbs from another verb type (e.g., path verbs) provided an estimate of attention during conjunctive learning to the attribute that distinguished those two verb types (e.g., manner).

Table 1 presents schematic descriptions of the five different test types. There were four trials of each of the five test types. The first three types—path, manner of motion, and conjunctive trials—involved events that were generated in the same way as events seen during learning. After each event, participants were asked to choose which of the six verbs was the best label for that event. One of the two verbs from the corresponding phase of learning was thus the correct answer in these trials. The fourth type, mismatch trials, involved events that depicted a combination of path and manner of motion that had not been presented during learning.

The fifth test type, the separated trials, was designed to ensure that participants represented path and manner as independent attributes during conjunctive learning. Because path and manner were perfectly correlated during conjunctive learning, participants could have represented path and manner as a single, conjoined attribute. For example, participants could have construed the path and the manner in the left column of Figure 2 as a zig-zagging path. If each manner of motion were subsumed into a complex path in this way, then participants could have defined conjunctive verbs in terms of these complex paths and differentiated conjunctive verbs from path verbs without reference to an independent manner of motion attribute.

The separated trials used a method analogous to that of Schyns and Rodet (1997) to test whether participants could distinguish conjunctive verbs from path verbs on the basis of an independent manner-of-motion attribute. In particular, path and manner of motion were presented as separate entities. Whereas the features in Schyns and Rodet's research were separated spatially, path and manner were separated in the present work by using two different objects to carry these two different types of motion. In particular, the agent carried the manner-of-motion attribute, just as it had throughout learning. The agent began the event oscillating in place, just as during the manner phase of learning. While it did this, however, a flying carpet, represented by a red square, flew underneath the agent and then carried the agent along on its path. The carpet flew along one of the two paths taken by the agent during learning. The agent started the event about halfway along the path from the carpet to the patient, thus allowing the carpet to start in motion independently of the agent and then pick it up. This

Table 1
Schematic Description of Stimuli From the Three Phases of Learning and From the Final Test Trials of Experiment 1

Event type	Stimulus 1	Stimulus 2
Learning phase		
Path	$P_1 M_0$	$P_2 M_0$
Manner	$P_0 M_1$	$P_0 M_2$
Conjunctive	$P_1 M_1$	$P_2 M_2$
Final test		
Path	$P_1 M_0$	$P_2 M_0$
Manner	$P_0 M_1$	$P_0 M_2$
Conjunctive	$P_1 M_1$	$P_2 M_2$
Mismatch	$P_1 M_2$	$P_2 M_1$
Separated	P_1 (Carpet) M_1	P_2 (Carpet) M_2

Note. Subscript numbers refer to the values of these attributes. A subscript 0 next to an attribute indicates that there was no variation on that attribute. The term *Carpet* after a path indicates that the path was taken by a flying carpet. P = path; M = manner.

was done to encourage the interpretation that the agent was not responsible for its own motion but rather was being carried by the carpet. The agent, however, continued to oscillate throughout the event while the carpet moved smoothly. The carpet thus represented the path attribute, whereas the agent represented manner of motion. The path and manner of motion were paired as they had been during the conjunctive phase of learning. Thus, a participant who represented conjunctive verbs in terms of separate path and manner attributes would be expected to choose conjunctive verbs as labels for the separated trials.

Procedure

Participants were instructed that they would be learning verbs from a language spoken on another planet. They were then presented with the first phase of learning. After each event, a button labeled *Next Event* appeared in the lower right-hand corner of the screen, allowing participants to continue on to the next event. After eight learning events, participants were given six criterion test trials. After the first event in each test trial, participants clicked on the *Next Event* button to see the second event. After the second event, participants clicked on one of two buttons labeled *First Event* and *Second Event* to indicate which event they thought was a better example of the verb accompanying those events. A third button labeled *Repeat* allowed participants to review the two events as many times as they wished. If participants were correct on all six events, they were allowed to continue on to the next phase of learning. If participants failed to achieve this criterion, they repeated the learning and test cycle up to two more times. This same procedure was followed for all three phases of learning. Different participants were presented with the three phases of learning in six different orders, representing all possible permutations of the path, manner, and conjunctive phases of learning. After completing the three phases of learning, participants were shown 20 final test trials. At the end of each event, participants chose one of six buttons, each labeled by an individual verb, to indicate which verb they thought was the best label for that event. The *Repeat* button also appeared, allowing participants to review an event as often as they wished.

Design

The primary dependent variable in this experiment was the percentage of correct conjunctive responses in the conjunctive and separated trials. The independent variables for this analysis were the order in which participants received the three phases of learning, manipulated between participants, and the type of test (conjunctive vs. separated), manipulated within participants. Additional dependent variables were the percentages of path and manner responses to the path, manner, and mismatch trials. The independent variable for these measures was learning order. A final dependent variable was the percent correct on criterion test events. The independent variables for this dependent variable were learning order and the type of verb being tested (i.e., path vs. manner vs. conjunctive).

Results

Criterion Test Trials

The results of the first block of criterion test events with each verb type are displayed in Figure 3. The relative difficulty of the different verb types provides a measure of attention to path and manner of motion. Because participants who performed with perfect accuracy in a block of criterion trials were moved on to the next phase of the experiment, not all participants completed three blocks of learning for each verb type (i.e., path, manner, and conjunctive). All participants completed at least one block of trials for each verb type, however, and thus an analysis of variance (ANOVA) could be performed on criterion test scores following the first block of learning with each verb type.

The effect of verb type was analyzed using two planned comparisons. The first comparison tested whether participants performed better when they could use path to make a discrimination, compared with when they could only use manner. In particular, performance with path verbs and

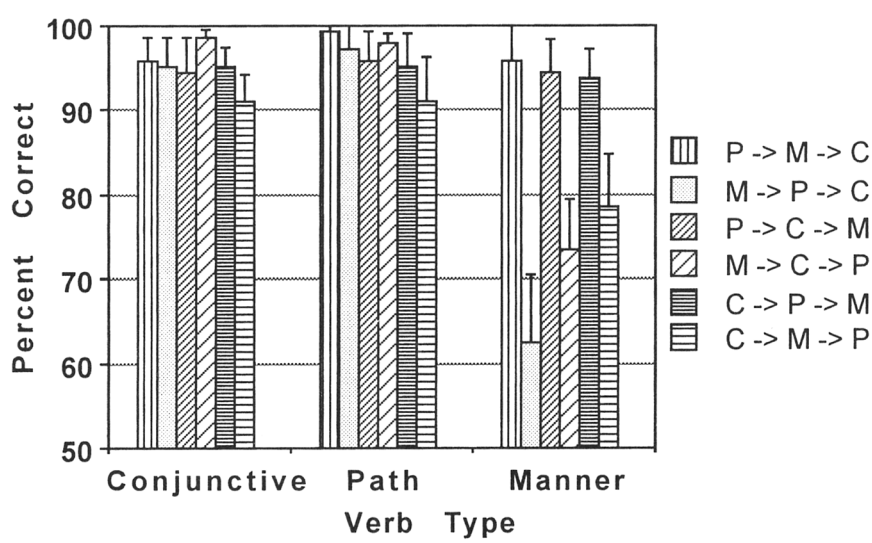

Figure 3. Results of the first block of criterion test trials for each verb type in Experiment 1. The six conditions reflect the six orders of learning (e.g., P → M → C = path → manner → conjunctive). Error bars reflect standard errors.

conjunctive verbs was compared with performance with manner verbs. This comparison revealed worse performance with manner verbs than with the other two verb types, $F(1, 138) = 23.65, p < .001, MSE = 628.37$, suggesting that path is indeed more salient than manner. The second comparison tested whether participants performed better when they could use both path and manner to make a discrimination, compared with when they could only use path. In particular, performance with conjunctive verbs was compared with performance with path verbs. This comparison revealed no differences between the two verb types, $F(1, 138) < 1$, suggesting that relevant variation on manner added little discriminability to conjunctive verbs above and beyond that provided by path.

There was also a significant effect of learning order on criterion test scores, $F(5, 138) = 4.95, p < .001, MSE = 345.74$, as well as a significant interaction of learning order with the comparison between manner verbs and the other two verb types, $F(5, 138) = 4.97, p < .001, MSE = 628.37$. The comparison between path verbs and conjunctive verbs, on the other hand, was not dependent on learning order, $F(5, 138) < 1$. To understand the cause of the significant effects involving learning order, post hoc Fisher's least significant difference (LSD) analyses compared the six learning orders on each verb type in isolation. These analyses revealed no significant differences on path and conjunctive verbs. There were, however, significant differences on manner verbs. In particular, participants in the Path–Manner–Conjunctive (PMC) and PCM conditions learned manner verbs more quickly than participants in the MPC, MCP, and CMP conditions; participants in the CPM condition performed better than participants in the MPC and MCP conditions; and participants in the CMP condition performed better than participants in the MPC condition. Thus, participants appear to have been better at learning manner verbs if they had already learned path verbs, compared with when they learned manner verbs first. This finding may reflect a pull on attention from novel variation on manner. In particular, manner did not vary when participants learned path verbs. When participants subsequently learned manner verbs, novel variation on manner was introduced. This novel variation may have drawn attention to manner, allowing participants to associate verbs with manners of motion.

Final Test Trials

Participants were selected for analysis of final test scores on the basis of performance in the criterion test trials. In particular, participants had to perform with 100% accuracy on at least one block of criterion test trials for each verb type to be included in analyses of final test scores. Out of the 24 participants in each condition, the numbers of participants in each condition who achieved this criterion were as follows: 24 in the PMC condition, 17 in the MPC condition, 24 in the PCM condition, 18 in the MCP condition, 24 in the CPM condition, and 18 in the CMP condition.

The percentages of correct conjunctive choices in the conjunctive and separated trials are depicted in Figure 4. These trials tested participants' abilities to discriminate conjunctive verbs from path verbs, providing a measure of attention to manner of motion during conjunctive learning. An ANOVA with trial type and learning order as independent variables revealed a main effect of learning order, $F(5, 119) = 4.98, p < .001, MSE = 1{,}163.01$. As predicted, participants who learned path or manner verbs prior to conjunctive verbs performed better than participants who learned conjunctive verbs first.

There was also a main effect of trial type, $F(1, 119) = 62.79, p < .001, MSE = 822.45$, with more correct conjunctive choices in the conjunctive trials than in the separated trials. This may indicate that some participants did not represent conjunctive verbs in terms of independent path and manner attributes. If they instead represented path and manner as a conjoined attribute, they may have rejected conjunctive verbs as labels for the separated trials because path and manner were portrayed separately in these trials. The interaction of Trial Type × Learning Order, however, did not approach significance, $F(5, 119) = 0.33, p > .10, MSE = 822.45$. Thus, any effects of learning order in this experiment cannot be explained by differences in representation because these effects were similar in the separated trials and in the conjunctive trials. These effects of learning order must therefore be a result of attentional mechanisms.

To test for effects of the two proposed attentional mechanisms on performance in the conjunctive and separated trials, we created a composite score of conjunctive verb learning by averaging each participant's z scores for these two measures. Two nonorthogonal planned comparisons were then carried out on these composite scores to test for effects of persistence and contrast on the learning of conjunctive verbs. An alpha level of .025 was adopted for each of these comparisons to maintain an overall alpha level of .05.

One comparison compared the PMC and MCP conditions with the PCM and CMP conditions, testing for effects of persistence on attention to manner during conjunctive learning. Each of the former conditions is identical to one of the latter conditions except that the order of learning manner and conjunctive verbs is reversed. Participants who learned manner verbs first were expected to subsequently attend more to manner in conjunctive learning as a result of persistence. The CPM and MPC conditions were not included in this comparison because path learning intervened between manner and conjunctive learning. As a result, it would have been impossible to determine whether changes in attention to manner were due to persistence, contrast, or both. This comparison was significant, $t(119) = 2.43, p < .025$, providing evidence for persistence. In particular, participants who learned manner verbs prior to conjunctive verbs made more correct conjunctive choices in the conjunctive and separated trials than did participants who learned conjunctive verbs before manner verbs.

The second comparison compared the MPC and PCM conditions with the MCP and CPM conditions, testing for effects of contrast on attention to manner during conjunctive learning. Each of the former conditions is identical to one of the latter conditions except that the order of learning path and conjunctive verbs is reversed. Participants who learned

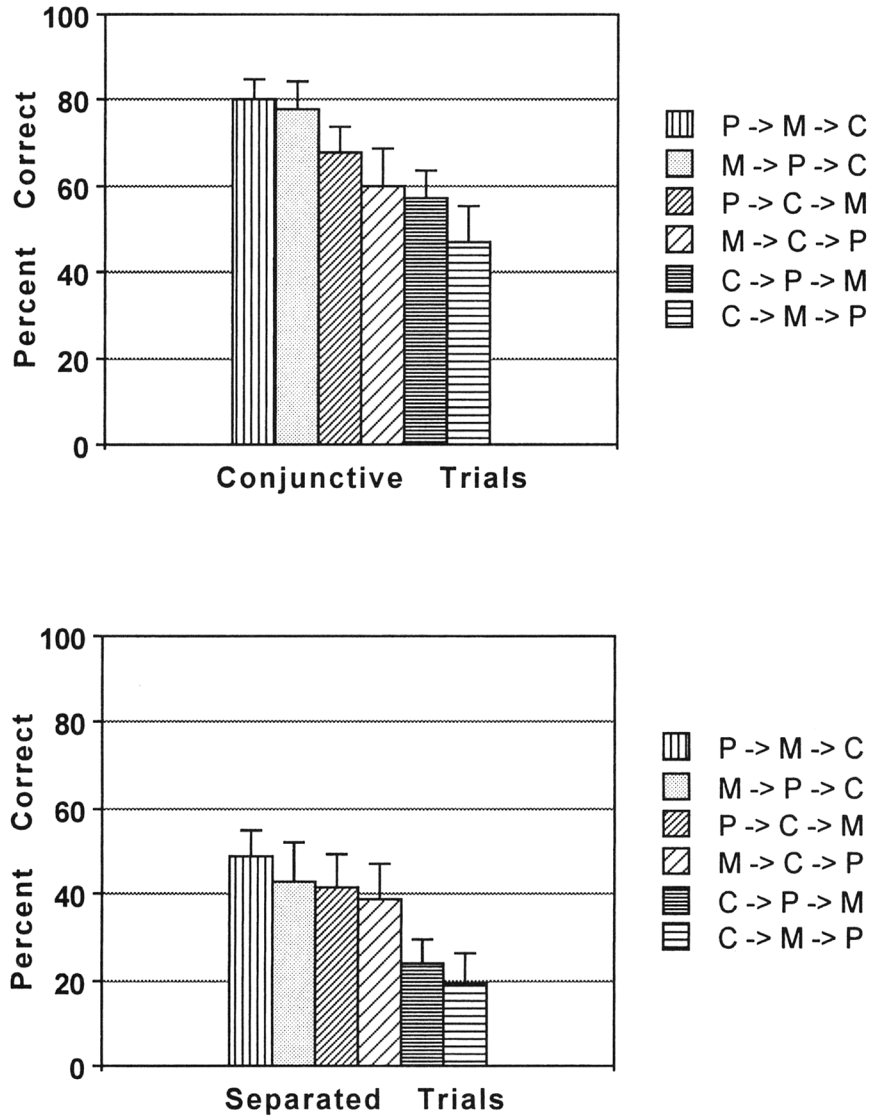

Figure 4. Percentage of correct conjunctive choices in the conjunctive and separated final test trials of Experiment 1. The six conditions reflect the six orders of learning (e.g., P → M → C = path → manner → conjunctive). Error bars reflect standard errors.

path verbs first were expected to attend more to manner in subsequent conjunctive verb learning as a result of contrast. The CMP and PMC conditions were not included in this comparison because manner learning intervened between path and conjunctive learning. This comparison was also significant, $t(119) = 2.34, p < .025$, providing evidence for contrast. In particular, participants who learned path verbs prior to conjunctive verbs made more correct conjunctive choices in the conjunctive and separated trials than did participants who learned conjunctive verbs before path verbs.

An analysis of incorrect responses in the conjunctive and separated trials revealed that participants who failed to choose correct conjunctive verbs most often chose a path verb. Such verbs conveyed the same paths as conjunctive verbs but did not convey the same manners of motion as did conjunctive verbs. Thus, a participant who chose a path verb instead of a conjunctive verb in these trials failed to notice the manner component of conjunctive verb meanings. The percentages of choices in the conjunctive and separated trials that matched the displayed event on path but mismatched on manner of motion are depicted in Figure 5. An ANOVA on these percentages revealed a significant main effect of test type, $F(1, 119) = 5.98, p < .05, MSE = 481.44$, with more path choices in the conjunctive trials than in the separated trials. There was also a significant main effect of learning order, $F(5, 119) = 4.93, p < .001, MSE = 805.25$. Participants who learned path or manner verbs before learning conjunctive verbs made fewer path verb choices than did participants who learned conjunctive verbs first. Test type again did not interact with learning order, $F(5, 119) = 0.70, p > .10, MSE = 481.44$.

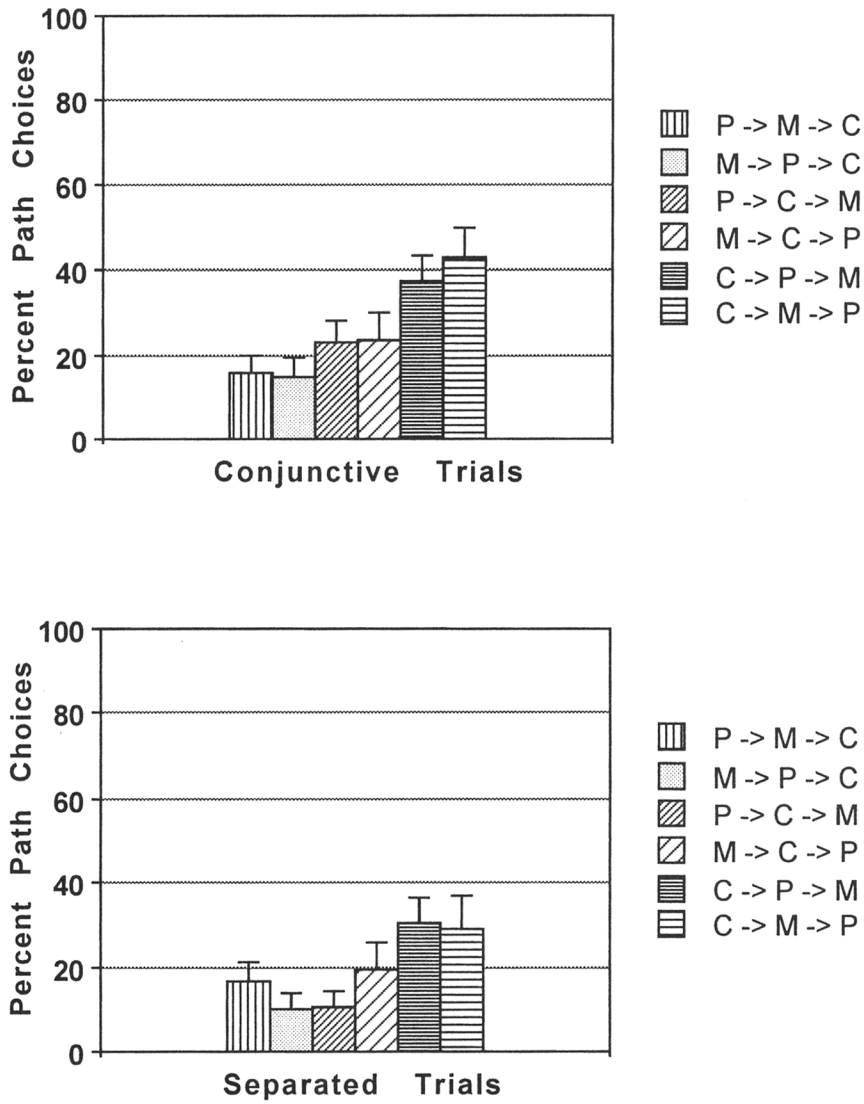

Figure 5. Percentage of choices in the conjunctive and separated final test trials of Experiment 1 involving path verbs that matched the test event on path but failed to predict the manner of motion displayed in the event. The six conditions reflect the six orders of learning (e.g., P → M → C = path → manner → conjunctive). Error bars reflect standard errors.

To understand the main effect of learning order on the percentages of path choices in the conjunctive and separated trials, we created a composite score of path verb choices by averaging each participant's z scores for path verb choices in the two trial types. The same two planned comparisons that are described earlier were performed to test for effects of persistence and contrast on these composite scores. The comparison testing for evidence of persistence examined whether participants who learned manner verbs prior to conjunctive verbs made fewer path verb choices in the conjunctive and separated trials. This prior learning of manner verbs was expected to increase attention to manner in conjunctive learning, allowing participants to better discriminate conjunctive verbs from path verbs. This effect of persistence approached significance, $t(119) = 1.71$, $p < .10$. The comparison testing for evidence of contrast examined whether participants who learned path verbs prior to conjunctive verbs made fewer path choices. This prior learning of path verbs was also expected to increase attention to manner in conjunctive learning, again allowing participants to discriminate conjunctive verbs from path verbs. This effect of contrast was significant, $t(119) = 2.94$, $p < .01$.

The results of the conjunctive and separated trials suggest that participants who learned path or manner verbs before conjunctive verbs were better able to differentiate path and conjunctive verbs. An alternative explanation, however, is that these data simply reflect a recency effect. In particular, participants who performed better in conjunctive and separated trials had learned conjunctive verbs more recently,

whereas participants who performed worse had learned path verbs more recently. The results of the path trials are inconsistent with this account, as can be seen in Figure 6. A one-way ANOVA on performance in the path trials revealed a significant main effect of learning order, $F(5, 119) = 3.40$, $p < .01$, $MSE = 2{,}952.90$. Post hoc Fisher's LSD tests revealed that participants in the PMC condition performed better than participants in the MCP, CPM, MPC, and CMP conditions, whereas participants in the PCM condition performed better than those in the CMP condition. Thus, the two groups that performed best on the path trials learned path verbs first. This finding is inconsistent with a recency account but consistent with contrast. In particular, participants who learned path verbs first attended more to manner in subsequent learning, allowing them to distinguish conjunctive verbs from path verbs.

There were no significant differences between conditions on the mismatch trials. The results of the manner trials revealed that participants who learned manner verbs first performed worse in the manner trials than did participants who learned path or conjunctive verbs first. Participants in the MCP and MPC conditions averaged 77.8% ($SD = 35.2\%$) and 80.9% ($SD = 30.0\%$), respectively, whereas participants in the CPM, CMP, PCM, and PMC conditions averaged 96.9% ($SD = 11.2\%$), 95.8% ($SD = 17.7\%$), 94.8% ($SD = 12.7\%$), and 92.7% ($SD = 17.3\%$), respectively. An ANOVA on the percentage of correct choices in these trials revealed a significant main effect of learning order, $F(5, 119) = 2.86$, $p < .05$, $MSE = 1{,}306.21$. Post hoc Fisher's LSD tests revealed that participants in the CPM, CMP, PCM, and PMC conditions performed better than those in the MCP condition, whereas participants in the CPM, CMP, and PCM conditions performed better than those in the MPC condition. These results are consistent with those of the criterion test trials, which also revealed difficulty in learning manner verbs prior to other verb types. Although all of the participants in the present analysis successfully completed the criterion test trials, their level of proficiency with these verbs may still have been less than that of participants who learned other verb types first. This lower level of proficiency with manner verbs may have caused participants who learned manner verbs first to have difficulty in the final test trials.

Discussion

The results of this experiment are consistent with the hypothesis that both attentional persistence and contrast can act to draw attention to an otherwise nonsalient attribute. The results of the criterion trials indicated that manner of motion was indeed less salient than path. In particular, participants had more difficulty learning to differentiate two verbs when manner was the only diagnostic attribute than when path was diagnostic.

The results of the final test trials revealed that attention to manner of motion could be increased as a result of attentional persistence and contrast. Participants who had learned either path verbs or manner verbs prior to conjunctive verb learning were better able to distinguish path verbs from conjunctive verbs in the conjunctive and separated trials. This ability to distinguish path verbs from conjunctive verbs was dependent on attention to manner of motion. The greater attention to manner of motion following manner verb learning is consistent with attentional persistence, whereas the greater attention to manner of motion following path verb learning is consistent with contrast.

Although the results of Experiment 1 are consistent with attentional persistence and contrast, an alternative explanation is possible for the contrast effects. In particular, when participants learned path verbs, manner of motion did not vary. Thus, when participants learned conjunctive verbs after path verbs, new variation on manner of motion was introduced. This new variation may have drawn attention to manner of motion independently of any effects of contrast. Evidence consistent with this alternative account comes

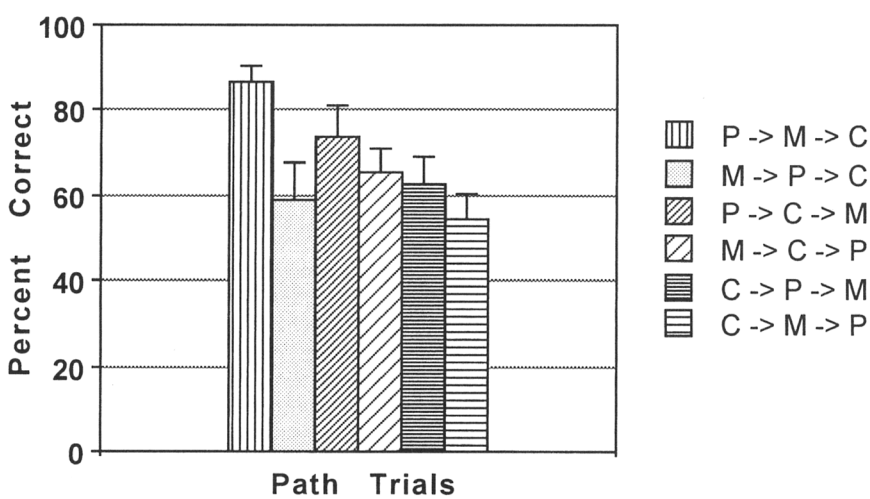

Figure 6. Percentage of correct path choices in the path final test trials of Experiment 1. The six conditions reflect the six orders of learning (e.g., P → M → C = path → manner → conjunctive). Error bars reflect standard errors.

from the criterion trials, in which participants were better able to learn manner verbs after they had already learned path verbs. Novel variation on manner was introduced when participants were transferred from path learning to manner learning, perhaps drawing attention to manner and thus allowing participants to better learn manner verbs. To provide evidence for contrast independently of any effects of novel variation on an attribute, Experiment 2 was designed to replicate the results of Experiment 1 while maintaining the amount of variation displayed by an attribute throughout learning.

Experiment 2

Experiment 2 differed from Experiment 1 in that all attributes that were not relevant to the meaning of a verb varied randomly during learning. For example, in the path phase of learning, manner varied independently of the accompanying verbs. Thus, no new variation on manner was added when participants were transferred from the path phase to the conjunctive phase of learning.

A second aim of Experiment 2 was to replicate the results of Experiment 1 but using a different type of motion to operationalize the less salient attribute. In particular, manner of motion acted as the less salient attribute for half of the participants and leg motion played this role for the other half. Kersten (1997) has proposed that manner of motion and leg motion are similar in that they are both examples of intrinsic motion, that is, motion defined with respect to a frame of reference internal to the object carrying out that motion. Prior experiments have revealed that the present leg motions, similar to the present manners of motion, receive less attention than the present paths in the context of verb learning (Kersten, 1998; Kersten & Billman, 1995). If persistence and contrast are general attentional processes, they should be able to draw attention to an attribute of low baseline salience regardless of the identity of that attribute. We thus predicted similar effects for leg motion and manner of motion.

Method

Participants

One hundred sixty-two undergraduates at Indiana University took part in this experiment in partial fulfillment of course requirements for introductory psychology.

Stimuli

Learning events. Table 2 shows a schematic description of the categories in Experiment 2. The learning events of Experiment 2 differed from those of Experiment 1 in that for half of the participants, leg motion rather than manner of motion was related to verb meaning. Manner of motion was relevant for the other half of the participants, as in Experiment 1. Because these two different types of intrinsic motion were used interchangeably, the phase of learning in which they were relevant is referred to as the *intrinsic motion phase.* In contrast to Experiment 1, in which manner of motion and path did not vary when only the other was relevant, in Experiment 2, path, manner of motion, and leg motion varied randomly when they were not relevant to verb meaning.

Table 2
Schematic Description of Stimuli From the Three Phases of Learning in Experiment 2

Learning phase	Verb 1 stimulus	Verb 2 stimulus
Intrinsic motion operationalized by leg motion		
Path	$P_1 L_{12} M_{12}$	$P_2 L_{12} M_{12}$
Intrinsic motion	$P_{12} L_1 M_{12}$	$P_{12} L_2 M_{12}$
Conjunctive	$P_1 L_1 M_{12}$	$P_2 L_2 M_{12}$
Intrinsic motion operationalized by manner of motion		
Path	$P_1 L_{12} M_{12}$	$P_2 L_{12} M_{12}$
Intrinsic motion	$P_{12} L_{12} M_1$	$P_{12} L_{12} M_2$
Conjunctive	$P_1 L_{12} M_1$	$P_2 L_{12} M_2$

Note. Subscript numbers refer to the values of these attributes. A subscript 12 following an attribute indicates that the attribute was nondiagnostic, taking each value in half of the examples of a verb. P = path; L = leg motion; M = manner of motion.

Criterion test trials. These differed from those of Experiment 1 in that there were only four criterion test trials after each block of learning events. All attributes that were not related to verb meaning in a particular phase of learning varied randomly across the two events in a test trial.

Final test events. The final test events were identical to those of Experiment 1 except that associations involving leg motion rather than manner of motion were tested for half of the participants. Trials testing for knowledge of either leg motion or manner of motion are referred to as the *intrinsic motion trials.*

Although path had varied randomly during the intrinsic motion phase of learning, path was not displayed in the intrinsic motion trials during the final test. This was done to ensure that only an intrinsic motion verb could be used as an appropriate label for these trials. Because all attributes that were not relevant to the meaning of a particular verb varied randomly during learning, the same combination of values of path, leg motion, and manner of motion could have been labeled not only by an intrinsic motion verb in the intrinsic motion phase of learning but also by a path verb in the path phase and a conjunctive verb in the conjunctive phase. As a result, if a random path had been chosen for each intrinsic motion trial, then participants could have correctly labeled each such event with either a path verb, an intrinsic motion verb, or a conjunctive verb. Because path was instead not displayed in the intrinsic motion trials, a participant who associated a verb with path should not have used this verb as a label for these trials. Thus, the percentage of conjunctive choices in the intrinsic motion trials could be used as a measure of attention to path during conjunctive learning.

Similarly, during the path trials, manner of motion was not displayed to participants for whom manner of motion was relevant during learning, whereas leg motion was not displayed to participants for whom leg motion was relevant during learning. As a result, a participant who associated a verb with intrinsic motion should not have used this verb as a label for the path trials. Thus, the percentage of conjunctive choices in the path trials could be used as a measure of attention to intrinsic motion during conjunctive learning.

As in Experiment 1, the conjunctive, separated, and mismatch trials displayed particular combinations of values of path and the relevant intrinsic motion attribute. Because each such combination could have been labeled during learning by a path verb and an intrinsic motion verb, as well as by a conjunctive verb, there was no

longer a correct answer in these trials. As a result, they were no longer diagnostic of attention to path and manner during conjunctive learning. They were included simply to retain as much as possible of the test procedure of Experiment 1.

Procedure

The procedure was identical to that of Experiment 1 except that there were only three learning orders: path–intrinsic motion–conjunctive (PIC), path–conjunctive–intrinsic motion (PCI), and conjunctive–path–intrinsic motion (CPI). In addition, only four criterion test trials followed each block of learning.

Design

The primary dependent variable in this experiment was the percentage of conjunctive responses in the path trials. This variable could be used as a measure of attention to intrinsic motion because participants would be able to reject conjunctive verbs and choose path verbs in these trials to the extent that they noticed the intrinsic motion components of conjunctive verbs. The independent variables for this analysis were the order in which participants received the three phases of learning (PIC vs. PCI vs. CPI) and the attribute used to operationalize intrinsic motion (leg motion vs. manner of motion). Both were manipulated between participants. A further dependent variable was the percent correct on criterion test events. The independent variables for this dependent variable were learning order and the attribute used to operationalize intrinsic motion, both manipulated between participants, as well as the type of verb being tested (i.e., path vs. intrinsic motion vs. conjunctive), which was manipulated within participants.

Results

Criterion Test Trials

The results of the first block of criterion test trials with each verb type are depicted in Figure 7. As in Experiment 1, the relative difficulty of the different verb types provides a measure of attention to path and intrinsic motion. Because all participants completed at least one block of learning for each verb type, the results of trials following the first block of learning with each verb type were analyzed in an ANOVA. The effect of verb type was again analyzed by using two planned comparisons. The first comparison revealed worse performance with intrinsic motion verbs than with path verbs and conjunctive verbs, $F(1, 156) = 127.77$, $p < .001$, $MSE = 858.36$. The second comparison revealed no significant differences between path verbs and conjunctive verbs, $F(1, 156) < 1$. There were no main effects or interactions involving learning order or the attribute used to operationalize intrinsic motion (all $Fs \leq 1.70$). These results were consistent with the work of Kersten (1998) and Kersten and Billman (1995) in showing that both leg motion and manner of motion are less salient than path in the context of verb learning.

Final Test Events

As in Experiment 1, participants were selected for analysis of final test scores if they performed with 100% accuracy on at least one block of criterion test trials for each verb type. Out of 27 participants in each condition, the numbers of participants in each condition who achieved this criterion were as follows: 14 in the PIC condition with manner of motion, 19 in the PIC condition with leg motion, 13 in the PCI condition with manner of motion, 19 in the PCI condition with leg motion, 13 in the CPI condition with manner of motion, and 17 in the CPI condition with leg motion.

The percentages of conjunctive choices in the path trials are depicted in Figure 8. These conjunctive verbs were consistent with the presented paths, but they had always been accompanied by particular intrinsic motions during learning that were not present in the path trials. Thus, the

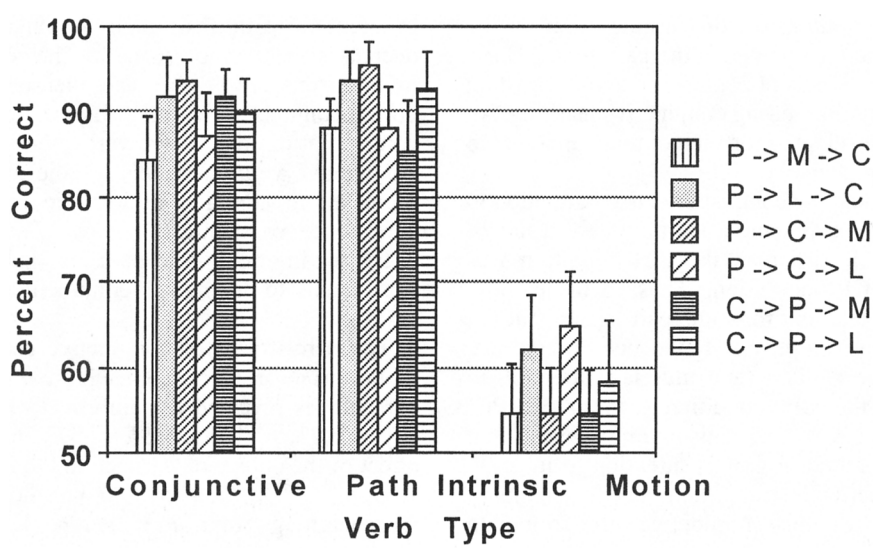

Figure 7. Results of the first block of criterion test trials for each verb type in Experiment 2. Error bars reflect standard errors. P = path; M = manner; C = conjunctive; L = leg motion.

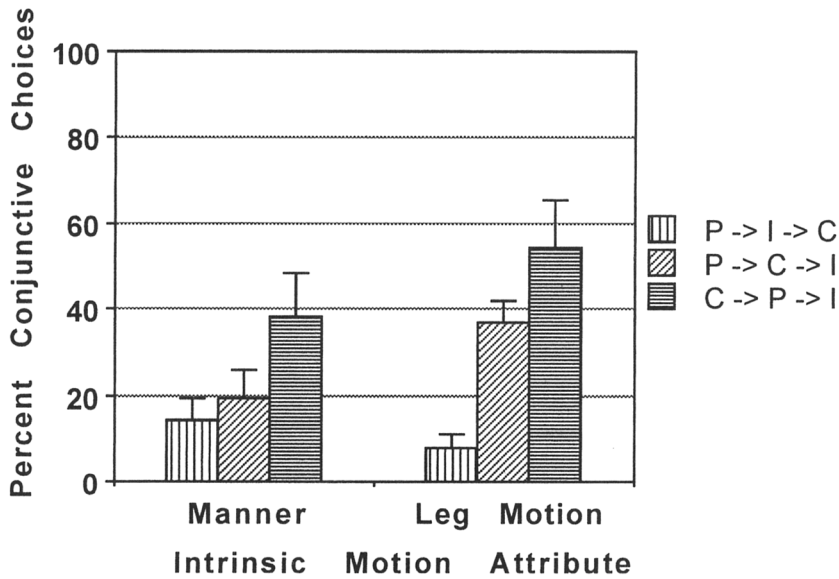

Figure 8. The percentages of conjunctive choices in the path final test trials of Experiment 2 that matched the presented event on its path component but mismatched on intrinsic motion. Error bars reflect standard errors. PIC = path → intrinsic motion (i.e., manner of motion or leg motion) → conjunctive; PCI = path → conjunctive → intrinsic motion; CPI = conjunctive → path → intrinsic motion.

extent to which participants chose conjunctive verbs rather than path verbs as labels for these trials can be used as a measure of attention to intrinsic motion during conjunctive learning. An ANOVA with learning order and intrinsic motion attribute as independent variables revealed a main effect of learning order, $F(2, 89) = 11.78, p < .001, MSE = 816.57$. There was no main effect of the choice of intrinsic motion attribute, $F(1, 89) = 2.32, p > .10, MSE = 816.57$, nor did this variable interact with learning order, $F(1, 89) = 1.74, p > .10, MSE = 816.57$.

Two nonorthogonal planned comparisons were carried out to understand the main effect of learning order on the percentages of conjunctive choices in the path trials. These comparisons tested for effects of persistence and contrast on attention to intrinsic motion during conjunctive learning. An alpha level of .025 was adopted for each of these analyses to preserve an overall alpha level of .05.

One comparison tested for contrast effects on attention to intrinsic motion during conjunctive learning as a result of prior path learning. In particular, the PCI condition was compared with the CPI condition. Thus, path learning preceded conjunctive learning for some participants but not for others. This comparison provided evidence for contrast, with more conjunctive choices (and thus less attention to intrinsic motion) in the CPI condition than in the PCI condition, $t(92) = 2.42, p < .025$. This finding suggests that prior path learning resulted in greater attention to intrinsic motion during conjunctive learning, helping participants in the PCI condition to distinguish conjunctive verbs from path verbs.

A second comparison tested for persistence to intrinsic motion during conjunctive learning as a result of prior intrinsic motion learning. In particular, the PIC condition was compared with the PCI condition. Thus, intrinsic motion learning preceded conjunctive learning for some participants but not for others. This comparison provided evidence for persistence, with more conjunctive choices (and thus less attention to intrinsic motion) in the PCI condition than in the PIC condition, $t(92) = 2.65, p < .01$. This finding suggests that prior intrinsic motion learning resulted in greater attention to intrinsic motion during conjunctive learning for participants in the PIC condition.

Given a fixed total pool of attentional resources, increases in attention to intrinsic motion would be accompanied by decreases in attention to path. The results of the intrinsic motion trials can be used as a measure of attention to path during conjunctive learning. If participants noticed the path component of conjunctive verbs, they should have rejected conjunctive verbs as labels for the intrinsic motion trials. Increases in attention to intrinsic motion as a result of persistence or contrast, however, may have resulted in decreases in attention to path, making it more difficult for participants to distinguish conjunctive verbs from intrinsic verbs.

The percentages of conjunctive choices in the intrinsic motion trials are depicted in Figure 9. An ANOVA on these percentages revealed a main effect of learning order, $F(2, 89) = 3.23, p < .05, MSE = 573.36$. There was no main effect of the choice of intrinsic motion attribute, $F(1, 89) = 1.53, p > .10, MSE = 573.36$, nor did this variable interact with learning order, $F(1, 89) < 1$. Two nonorthogonal planned comparisons were carried out to understand the main effect of learning order on the percentages of conjunctive choices in the intrinsic motion trials. One comparison

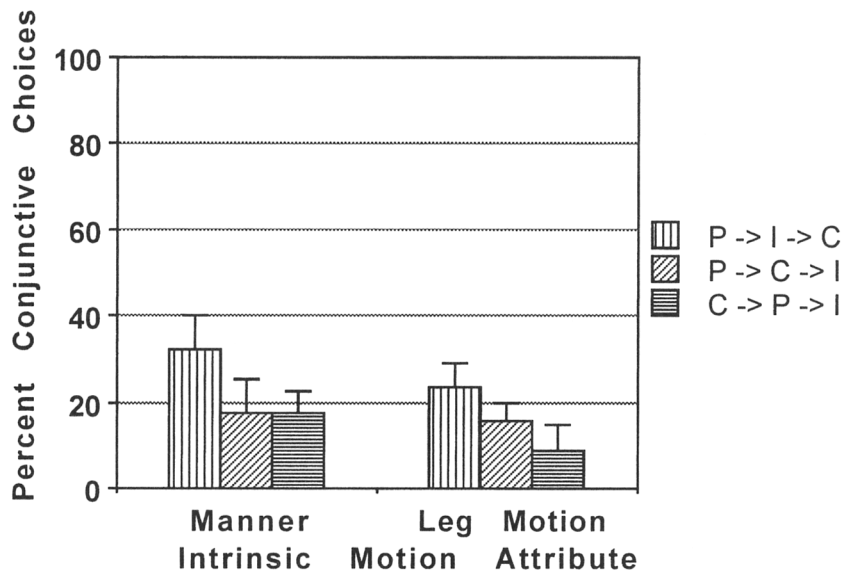

Figure 9. The percentages of conjunctive choices in the intrinsic motion final test trials of Experiment 2 that matched the presented event on its path component but mismatched on path. Error bars reflect standard errors. PIC = path → intrinsic motion (i.e., manner of motion or leg motion) → conjunctive; PCI = path → conjunctive → intrinsic motion; CPI = conjunctive → path → intrinsic motion.

examined whether persistence to leg motion resulted in a decrease in attention to path. This comparison compared the PIC and PCI conditions. Thus, intrinsic motion learning preceded conjunctive learning for some participants but not for others. The results of this analysis approached significance, $t(92) = 1.84$, $p < .07$, with a trend toward more conjunctive choices (and thus less attention to path) in the PIC condition than in the PCI condition. Thus, prior intrinsic motion learning may have resulted in less attention to path during conjunctive learning for participants in the PIC condition.

A second comparison examined whether increases in attention to intrinsic motion because of contrast resulted in decreases in attention to path. This comparison compared the PCI and CPI conditions. Thus, path learning preceded conjunctive learning for some participants but not for others. This comparison was not significant, $t(92) = 0.65$, $p > .10$. Thus, although there is evidence that prior path learning resulted in greater attention to intrinsic motion because of contrast, Experiment 2 does not provide evidence that this prior learning resulted in decreases in attention to path.

Discussion

As in Experiment 1, participants were better able to distinguish path and conjunctive verbs when conjunctive verbs were learned after path or intrinsic motion verbs. Participants who learned path verbs before conjunctive verbs made fewer conjunctive responses in the path trials than did participants who learned conjunctive verbs first. This provides evidence for contrast in that participants were more likely to notice the intrinsic motion component of conjunctive verbs as a result of prior path learning. Participants who learned intrinsic motion verbs before conjunctive verbs made fewer incorrect conjunctive responses in the path trials than did participants who learned conjunctive verbs before intrinsic motion verbs. This provides evidence for persistence, in that participants were more likely to notice the intrinsic motion component of conjunctive verbs as a result of prior intrinsic motion learning.

Experiment 2 also provided evidence that increases in attention to leg motion because of persistence resulted in decreases in attention to path. Experiment 2 did not provide evidence, however, that increases in attention to leg motion as a result of contrast are also associated with decreases in attention to path. It is possible that a floor effect was responsible for this lack of effect. Experiment 3 more systematically tested whether increases in attention to one attribute because of persistence and contrast result in decreases in attention to other attributes.

Experiment 3

Experiment 3 was designed to test the hypothesis that persistence operates primarily at the level of attributes, whereas contrast operates at the level of attribute values. To provide evidence for persistence to attributes, we compared a control condition in which conjunctive verbs were learned first with two conditions in which leg motion verbs were learned prior to conjunctive verbs (see Table 3). If persistence operates at the level of attributes, then prior learning of leg motion verbs should result in greater attention to leg motion during subsequent conjunctive learning. As a result, participants in the control condition were expected to attend

Table 3
Schematic Description of the Three Learning Conditions in Experiment 3

Condition	Phase 1 categories	Phase 2 categories	Phase 3 categories
Control	$P_1 L_1$ vs. $P_2 L_2$ (Conjunctive)	$P_{12} L_1$ vs. $P_{12} L_2$ (Identical leg motion)	$P_{12} L_3$ vs. $P_{12} L_4$ (Different leg motion)
Persistence	$P_{12} L_3$ vs. $P_{12} L_4$ (Different leg motion)	$P_1 L_1$ vs. $P_2 L_2$ (Conjunctive)	$P_{12} L_1$ vs. $P_{12} L_2$ (Identical leg motion)
Contrast	$P_{12} L_1$ vs. $P_{12} L_2$ (Identical leg motion)	$P_1 L_1$ vs. $P_2 L_2$ (Conjunctive)	$P_{12} L_3$ vs. $P_{12} L_4$ (Different leg motion)

Note. Subscript numbers represent values of leg motion and path. A subscript 12 following an attribute indicates that the attribute was nondiagnostic, taking each value in half of the examples of a verb. Each phase of learning is labeled by parenthetical text appearing beneath the schema for that phase. P = path; L = leg motion.

less to leg motion during conjunctive learning than were participants in the other two conditions.

To provide evidence for contrast to attribute values, the two conditions involving prior leg motion verb learning varied in the particular values of leg motion that were used. In the persistence condition, different values of leg motion were involved in conjunctive verb learning and prior leg motion learning. Because the values of leg motion displayed during conjunctive learning had not been encountered before in this condition, no contrast effects were expected to counteract effects of persistence to leg motion as an attribute. In the contrast condition, the same values of leg motion were involved in conjunctive verb learning and prior leg motion verb learning. Because the two values of leg motion displayed during conjunctive learning would already have been associated with categories, contrast effects were expected to partially offset any effects of persistence in this condition. Thus, participants were expected to attend less to leg motion in the contrast condition than in the persistence condition.

Method

Participants

One hundred sixty-eight undergraduates at Indiana University took part in this experiment in partial fulfillment of course requirements for introductory psychology.

Stimuli

Learning events. There were three phases of learning. In the conjunctive phase, each of the two verbs labeled a particular combination of path and leg motion. In the identical leg motion phase, each of the two verbs labeled a leg motion that was identical to the leg motions presented in the conjunctive phase. In the different leg motion phase, each of the two verbs labeled a leg motion different from the two that were presented in the conjunctive phase. Path varied orthogonally to verb meaning in both leg motion phases of learning. Thus, a verb from one of the leg motion phases of learning could be accompanied by either of the two paths but was always accompanied by the same leg motion.

Participants in the control condition received the conjunctive phase first, followed by the identical leg motion phase and then the different leg motion phase. Participants in the persistence condition received the different leg motion phase first, followed by the conjunctive phase and then the identical leg motion phase. Participants in the contrast condition received the identical leg motion phase first, followed by the conjunctive phase, and then the different leg motion phase.

Criterion test trials. These were generated in the same way as those in Experiment 2.

Final test events. These were different from those of Experiment 2 in that only two verbs were presented as possible labels for each event. There were seven different test types. Table 4 shows a schematic description of the final test types. Three tested for attention to leg motion. In the first type (Leg Motion 1), no path was shown. The agent sat in place moving its legs in a particular leg motion. Participants chose between the two conjunctive verbs, one consistent with the presented leg motion and one inconsistent. In the second type (Leg Motion 2), a path and leg motion from the conjunctive phase were presented but were paired differently than in the conjunctive phase. Participants chose between a conjunctive verb consistent with the presented path but inconsistent with the presented leg motion and a verb from the identical leg motion phase that was consistent with both the leg motion and path. Making this second choice would indicate attention to leg motion. In the third type (Leg Motion 3), a path from the conjunctive phase and a leg motion from the different leg motion phase were presented. Participants chose between a verb from the conjunctive phase consistent with the path but inconsistent with the leg motion and a verb from the different leg motion phase consistent with both leg motion and path. Making this second choice would indicate attention to leg motion.

Four test types measured attention to path. In the first type (Path 1), no leg motion was shown. The agent moved along its path while holding its legs stationary. Participants chose between two conjunctive verbs, one consistent with the presented path and one inconsistent. In the second type (Path 2), a path and leg motion from the conjunctive phase were presented but were paired differently than in the conjunctive phase. Participants chose between a conjunctive verb consistent with leg motion but inconsistent with path and a leg motion verb that was consistent with both path and leg motion. Making this second choice would indicate attention to path. In the third type (Path 3), path was not represented. Participants chose between a conjunctive verb that was consistent with the presented leg motion but also made predictions for path and a leg motion verb that was consistent with the presented leg motion; participants made no predictions for path. Making this second choice would indicate attention to path. In the fourth type (Path 4), a path and leg motion from the conjunctive phase were presented, paired in the same way as in the conjunctive phase. Participants chose between a conjunctive verb and an identical leg motion verb, both of which were consistent with both

Table 4
Schematic Description of the Test Stimuli in Experiment 3

Learning stimulus	Verb	Test type	Stimulus	Verb choice
P_1L_1	morping	Leg Motion 1	P_0L_1	morping or wunking
P_2L_2	wunking	Leg Motion 1	P_0L_2	morping or wunking
$P_{12}L_1$	spogging	Leg Motion 2	P_1L_2	morping or zelling
$P_{12}L_2$	zelling	Leg Motion 2	P_2L_1	wunking or spogging
$P_{12}L_3$	yimming	Leg Motion 3	P_1L_3	morping or yimming
$P_{12}L_4$	gupping	Leg Motion 3	P_1L_4	morping or gupping
		Leg Motion 3	P_2L_3	wunking or yimming
		Leg Motion 3	P_2L_4	wunking or gupping
		Path 1	P_1L_0	morping or wunking
		Path 1	P_2L_0	morping or wunking
		Path 2	P_1L_2	wunking or zelling
		Path 2	P_2L_1	morping or spogging
		Path 3	P_0L_1	morping or spogging
		Path 3	P_0L_2	wunking or zelling
		Path 4	P_1L_1	morping or spogging
		Path 4	P_2L_2	wunking or zelling

Note. Subscript numbers represent values of leg motion and path. A value of 0 indicates that the value of that attribute was not represented in the stimuli. P = path; L = leg motion.

path and leg motion. The conjunctive verb specifically predicted the presented path, however, whereas the leg motion verb made no predictions for path. Thus, participants were expected to choose the conjunctive verb to the extent that they attended to the path components of these verbs.

Procedure

The procedure was identical to that of Experiment 2 except that there were 32 final test trials. Each of the 16 test types listed in Table 4 was presented twice.

Design

The primary dependent measures were the percentages of correct responses to the 7 different final test types. The independent variable for these analyses was learning order (control vs. persistence vs. contrast). A second dependent variable was performance in the criterion test trials. The independent variables for this analysis were learning order and the type of verb being tested (conjunctive vs. different leg motion vs. identical leg motion).

Results

Criterion Test Trials

The results of the first block of criterion test trials with each verb type are displayed in Figure 10. As in Experiments 1 and 2, the relative difficulty of the different verb types provides a measure of attention to path and leg motion. These results were analyzed in an ANOVA with learning order and verb type as independent variables. This analysis

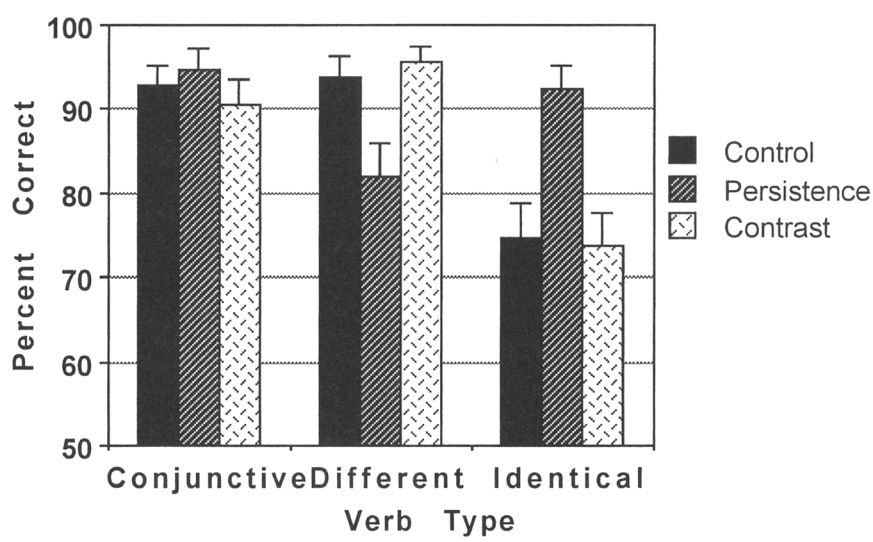

Figure 10. Results of the first block of criterion test trials for each verb type in Experiment 3. Error bars reflect standard errors.

revealed no main effect of learning order, $F(2, 165) < 1$. The effect of verb type was analyzed using two planned comparisons. The first comparison compared the learning of conjunctive verbs with the learning of the two types of leg motion verbs. Conjunctive verbs were expected to be easier because these verbs could be differentiated on the basis of path. This comparison revealed better performance with conjunctive verbs than with the two types of leg motion verbs, $F(1, 165) = 14.96$, $p < .001$, $MSE = 406.17$. This comparison was not dependent on learning order, as indicated by the absence of an interaction, $F(2, 165) < 1$.

The second comparison compared the learning of identical leg motion verbs with the learning of different leg motion verbs. This comparison revealed better learning of different leg motion verbs, $F(1, 165) = 13.69$, $p < .001$, $MSE = 647.08$. This comparison was also dependent on learning order, as indicated by a significant interaction, $F(2, 165) = 13.76$, $p < .001$, $MSE = 647.08$. Post hoc LSD tests were conducted separately on the two types of leg motion verbs to understand these effects. An analysis of identical leg motion verbs revealed that participants in the persistence condition performed better than participants in the other two conditions, which did not differ. This advantage of the persistence condition may reflect persistence to leg motion as a result of prior learning of different leg motion verbs. Participants in the other two conditions learned identical leg motion verbs before different leg motion verbs. An analysis of different leg motion verbs revealed that participants in the persistence condition performed worse than did participants in the other two conditions, which did not differ. This advantage of the control and contrast conditions is also consistent with persistence to leg motion. Participants in these conditions learned identical leg motion verbs prior to different leg motion verbs, whereas participants in the persistence condition learned different leg motion verbs first.

Final Test Trials

As in Experiments 1 and 2, participants were selected for analysis of final test scores if they performed with 100% accuracy on at least one block of criterion test trials for each verb type. Out of 56 participants in each condition, the numbers of participants in each condition who achieved this criterion were as follows: 43 in the control condition, 50 in the persistence condition, and 46 in the contrast condition.

The results of the three different tests of attention to leg motion are depicted in Figure 11. The effects of learning order on performance in the leg motion trials were analyzed using two orthogonal planned comparisons. The first comparison tested for attentional persistence. This comparison compared the control condition with the persistence and contrast conditions. These last two conditions were grouped together in this analysis because they both had a leg motion phase of learning prior to conjunctive learning. This would be expected to draw attention to leg motion as an attribute. Analyzing Leg Motion 1 trials in this way revealed significant persistence, $t(136) = 3.41$, $p < .001$, with less attention to leg motion in the control condition compared with the other two conditions. The analysis of Leg Motion 2 trials did not reveal significant persistence, although the trend was in the predicted direction, $t(136) = 0.80$, $p > .10$. Leg Motion 3 trials also failed to reveal significant persistence. This lack of effect was apparently a result of a ceiling effect, with nearly perfect performance in all three conditions.

The second planned comparison tested for contrast. This comparison compared the persistence condition with the contrast condition. These two conditions varied in the particular values of leg motion that were used. Participants in the contrast condition saw the same values of leg motion in the first phase of learning and in subsequent conjunctive learning. Participants in the persistence condition saw different values of leg motion in the first phase of learning

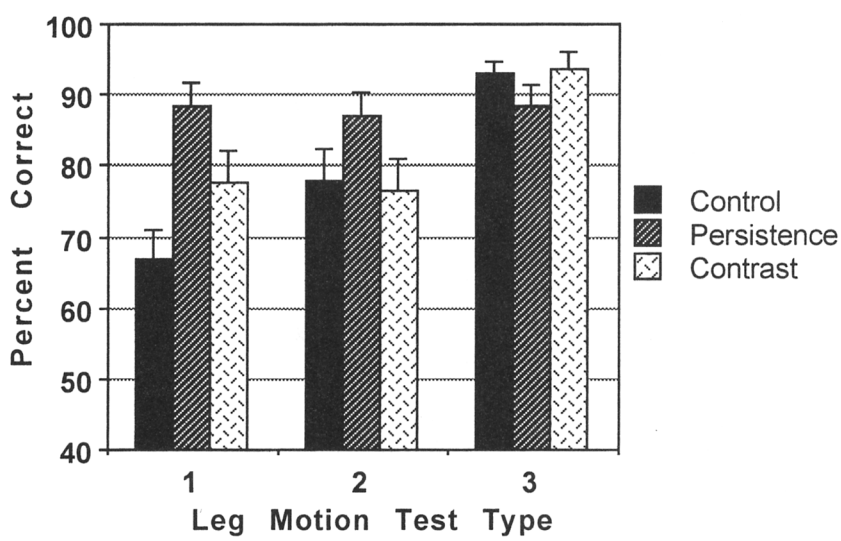

Figure 11. Results of the leg motion final test trials in Experiment 3. Error bars reflect standard errors.

and in subsequent conjunctive learning. Thus, contrast effects were expected in the contrast condition but not in the persistence condition. Analyzing the Leg Motion 1 trials in this way revealed evidence for contrast, $t(136) = 2.04, p < .05$, with greater attention to leg motion in the persistence condition than in the contrast condition. The effect of contrast in the Leg Motion 2 trials approached significance, $t(136) = 1.90, p < .06$. There was no significant effect of contrast in the Leg Motion 3 trials, again apparently because of a ceiling effect.

The results of the four different tests of attention to path are depicted in Figure 12. Increases in attention to leg motion as a result of persistence and contrast would be expected to be accompanied by corresponding decreases in attention to path, if one assumes that the total amount of attention is fixed. Two orthogonal planned comparisons again tested for persistence and contrast effects in these trials. Effects of persistence to leg motion were revealed in the Path 1 trials, $t(136) = 4.25, p < .001$; Path 2 trials, $t(136) = 2.73, p < .01$; and Path 3 trials, $t(136) = 3.38, p < .001$. Participants attended less to path in the persistence and contrast conditions than in the control condition. There was no significant effect of persistence on the Path 4 trials. This lack of effect most likely stems from the fact that both a conjunctive verb and a leg motion verb could be correctly used to label these trials. Participants apparently chose at random from these two verbs, resulting in a floor effect.

The results of the path trials were also analyzed for effects of contrast on attention to leg motion. The effect of contrast did not reach significance in the Path 1 trials, $t(136) = 0.83$, $p > .10$, although the trend was in the predicted direction. There was a significant effect of contrast in the Path 2 trials, $t(136) = 1.98, p < .05$, with greater attention to path in the contrast condition than in the persistence condition. There were no significant effects of contrast in the Path 3 or Path 4 trial.

Discussion

Experiment 3 provides evidence that attentional persistence operates at the level of attributes, whereas contrast effects are realized at the level of attribute values. In particular, persistence following leg motion training resulted in increased attention to leg motion and decreased attention to path, compared with a control condition that was given no prior leg motion training. If the same values of leg motion were seen in the first two phases of learning, however, contrast resulted in decreased attention to leg motion and increased attention to path, compared with a condition in which different values of leg motion were seen in the first two phases.

Although the results of Experiment 3 are generally quite consistent with both persistence and contrast, not every test type revealed evidence for both attentional mechanisms. The null results of Leg Motion 3 and Path 4 trials can be quite easily explained in terms of ceiling and floor effects, respectively. Even the remaining test types, however, differ in the extent to which they reveal persistence and contrast. For example, the Leg Motion 1 trials reveal a greater amount of persistence than do the Leg Motion 2 trials, even though the two types of trials are conceptually similar. In addition, the Path 2 trials reveal a greater amount of contrast than do the Path 1 trials, whereas the Path 3 trials did not reveal even a trend toward contrast. At present, it is unclear why the magnitude of persistence and contrast effects differed across these different test types.

The results of Experiment 3 are for the most part consistent with a model in which the total pool of attention is fixed (e.g., Nosofsky, 1986; Sutherland & Mackintosh, 1971). In such a model, increases in attention to one attribute result in decreased attention to other attributes. In Experiment 3, increases in attention to leg motion were apparently accompanied by decreases in attention to path. The most

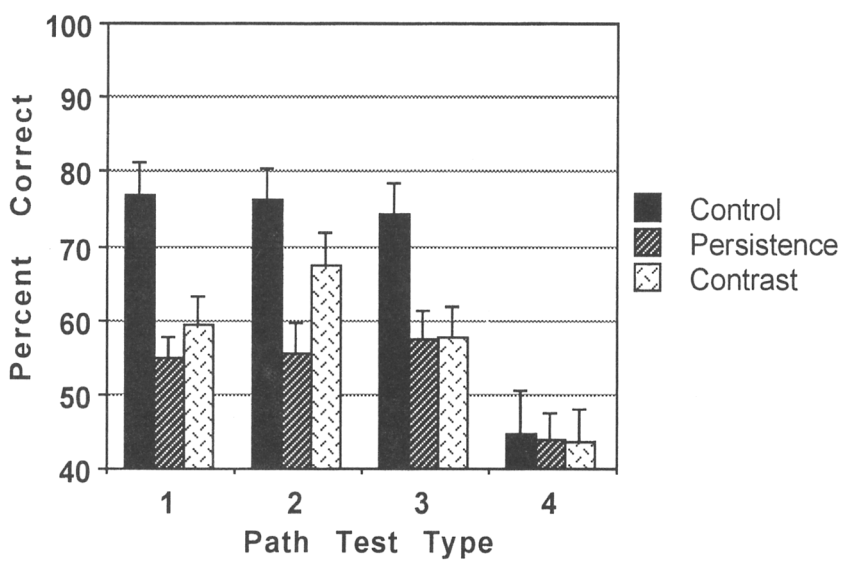

Figure 12. Results of the path final test trials in Experiment 3. Error bars reflect standard errors.

straightforward comparison of attention to leg motion and path involves the Leg Motion 1 and Path 1 trials, which were highly analogous. Such a comparison revealed that the total amount of attention to leg motion and path was quite similar across the three conditions, even though the distribution of attention over these two attributes varied considerably. This null finding, however, does not disconfirm models that allow changes in the total pool of attention (e.g., Mackintosh, 1975).

General Discussion

The present experiments provide evidence for two competing attentional mechanisms. Attentional persistence serves to increase attention to attributes previously found to be predictive. Contrast serves to increase attention to attribute values whose predictive power has yet to be discovered. In Experiment 1, we demonstrated that attention to manner of motion, an attribute whose salience was initially low, could be increased as a result of prior training in which manner of motion was relevant. This finding provides evidence for attentional persistence. Attention to manner was also increased following path training, providing evidence for contrast. The interpretation of contrast effects in Experiment 1, however, was complicated by the fact that manner of motion did not vary when only path was relevant. Thus, increased attention to manner following path learning could have simply reflected attention to novel variation on manner. Experiment 2 provided evidence for contrast by using a design in which no new variation on an attribute was introduced. Experiment 3 provided evidence that persistence operates primarily at the level of attributes, whereas contrast operates primarily at the level of attribute values.

Feature Creation and Attentional Mechanisms

Although the present task is similar to the task Schyns and Rodet (1997) used to provide evidence for feature creation, the current results can be explained entirely in terms of changes in attention weights. Feature creation and attentional mechanisms may, however, play intimately related roles in categorization. When confronted with a novel category label, a categorizer may look first to his or her existing featural repertoire to determine whether any of those features can be found in the sensory environment. Attentional persistence may encourage the sampling of features from some attributes over others. At the same time, contrast may direct attention to features that have not already been associated with a category. If there are no existing features that match the present situation and are not associated with a category, contrast may encourage the creation of a new psychological feature based on some salient physical property of the present environment. Attentional persistence may again play a role in this process of feature creation, determining which physical properties are most salient. For example, after learning a number of words that refer to shape, a child may be more likely to create a new shape feature to categorize a novel object. An association can then be created between this new feature and its corresponding category.

The contrast mechanism proposed in the present article assumes the presence of features that have not already been associated with a category. If new features are only created when they are necessary to distinguish a new category from existing categories, then the present contrast mechanism is identical to the feature creation mechanism proposed by Schyns and Rodet (1997). If this were the case, all features in a learner's featural repertoire would already have been associated with categories. As a result, contrast would require the creation of a new feature to distinguish a new category from existing categories. On the other hand, it is possible that features are created for salient physical properties of the environment even if those features do not yet distinguish between categories. If this were the case, the present contrast mechanism would not require the creation of novel features but rather could direct attention to existing features that have not already been associated with a category.

This account of categorization becomes more complex if one views the identification of feature as a categorization problem in its own right (see, e.g., Schyns, Goldstone, and Thibaut, 1998). The confidence with which one categorizes a feature may influence the magnitude of the shifts in attention associated with persistence and contrast. For example, the two different path features in the present experiments were quite different, with one path involving a straight line and the other involving a 90° turn. As a result, when a novel category label was presented along with a path that was already associated with a different category, participants were likely to shift attention to the values of other attributes because of contrast. This tendency may have been weaker if a novel category label had been presented along with a path that was similar but not identical to a path that was already associated with a category. In particular, participants may have been less likely to shift attention because they were less confident that this new path was an example of the previously presented category of paths. Further research involving quantitatively varying features could be used to examine this issue.

The Role of Contrast in the Acquisition of Nouns and Relational Terms

Previous work with children has revealed a bias to associate novel words with novel referents (e.g., Markman & Wachtel, 1988). For example, once the shape of an object is associated with a label, children focus on other information such as the substance of the object when presented with a new word. The present work shows that this tendency can be seen in adults as well as children. For example, once a path of an object was associated with a label, adults focused on other information such as the manner of an object when presented with a new word. This finding is important because a bias to associate novel words with novel referents has been regarded as an immature word-learning strategy that must be overcome to acquire the full expressive power of language. For example, a child must overcome this

tendency to learn that a *horse* is also an *animal*. Although the same object or action can be labeled by many different words in the adult lexicon, adults retain a tendency to focus on new information when presented with a new word.

The present research with adults is consistent with previous work with children in revealing a tendency to associate novel verbs with novel actions (Golinkoff, Jacquet, Hirsh-Pasek, & Nandakumar, 1996; Merriman, Evey-Burkey, Marazita, & Jarvis, 1996; Merriman, Marazita, & Jarvis, 1993). Unlike in the present work, however, these past researchers have manipulated whether or not an entire event was already associated with a label. In the present experiments, we manipulated whether or not an individual attribute value had been labeled.

The manipulation of novelty at the level of entire events may explain why Merriman et al. (1993) observed a smaller bias to associate verbs with novel referents than to associate nouns with novel referents. The same event can be labeled by many different verbs depending on which attribute of the event is being focused on (Huttenlocher & Lui, 1979; Kersten & Billman, 1997). For example, an event in which a person walks into a store can be labeled equally well by *walking* or *entering*. In contrast, although nouns can have different labels corresponding to different levels in a hierarchy (e.g., *bird* or *animal*), the basic level tends to be strongly preferred. As a result, an object is labeled by the same basic-level noun on most occasions. Thus, if a familiar object is presented along with a novel noun, it is likely that the noun refers to something other than that object. If a familiar event is presented along with a novel verb, however, it is possible that the verb refers to some other attribute of the same event.

When learning verbs, contrast at the level of attribute values may thus be more useful than contrast at the level of entire events. Contrast among attribute values may be particularly useful in learning English verbs because such verbs often refer to the manner of motion of an object (Talmy, 1985). As has been demonstrated in this and previous research (Kersten, 1997), manner of motion is less salient than path in the context of verb learning. Indeed, children learning English, as well as other quite different languages such as Korean, tend to learn path terms before manner-of-motion terms (Choi & Bowerman, 1991). The present research suggests that this learning of path terms may allow children to redirect attention away from path and toward other attributes of an event such as manner of motion. Thus, attentional contrast may assist in the learning of manner-of-motion verbs.

Conclusions

This research provides evidence for two competing attentional mechanisms. Persistence seems to operate at the level of attributes, serving to draw attention to attributes that have previously been predictive of an outcome, regardless of the values of that attribute. Contrast seems to operate at the level of attribute values, serving to divert attention away from values that are already associated with a category or response. The combined influences of these two mechanisms determine the overall amount of attention allocated to an attribute.

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Received June 9, 1997
Revision received March 23, 1998
Accepted April 3, 1998 ■