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13. ABSTRACT (Maximum 200 words)

Yee, Hunt, & Pellegrino (1991) introduced the concept of information coordination tasks - tasks that require the concurrent performance of two or more component tasks and the subsequent coordination of component information. In the present experiment different procedures, componential and contextual, were used to train separate groups (N=35, N=33) in a coordination task that involved dynamic spatial and verbal components. Within and between group analyses indicated that posttraining performance improved and the improvement was equivalent across treatments. However, individual differences analyses indicated the treatments promoted different ability-performance profiles, which were related to differential dependencies on working memory resources. The differential dependence on working memory appears related to the functional consistency of information (e.g., Carlson & Lundy, 1992) in the different treatments. Further analyses indicated that both treatments fostered the coordination of the dynamic spatial information within the relative arrival time task - a dynamic spatial coordination task (Law et al., in-press). Sensitivity to relative velocity, working memory capacity, verbal processing ability, and gender mediated whether individuals became coordinators of dynamic spatial information. The broad implications of this study include the importance of combining mean and individual differences analyses in studies of human cognition.

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Complex Information Coordination Performance: Differential Changes in Working Memory Contributions Following Training

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Vanderbilt University

Final Report

June 30, 1993

Cognitive Components of Information Coordination

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Principal Investigator

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Abstract

Yee, Hunt, & Pellegrino (1991) introduced the concept of information coordination tasks - tasks that require the concurrent performance of two or more component tasks and the subsequent coordination of component information. In the present experiment different procedures, componential and contextual, were used to train separate groups (N=35, N=33) in a coordination task that involved dynamic spatial and verbal components. Within and between group analyses indicated that posttraining performance improved and the improvement was equivalent across treatments. However, individual differences analyses indicated the treatments promoted different ability-performance profiles, which were related to differential dependencies on working memory resources. The differential dependence on working memory appears related to the functional consistency of information (e.g., Carlson & Lundy, 1992) in the different treatments. Further analyses indicated that both treatments fostered the coordination of the dynamic spatial information within the relative arrival time task - a dynamic spatial coordination task (Law et al., in-press). Sensitivity to relative velocity, working memory capacity, verbal processing ability, and gender mediated whether individuals became coordinators of dynamic spatial information. The broad implications of this study include the importance of combining mean and individual differences analyses in studies of human cognition.

Yee, Hunt, and Pellegrino (1991) described a class of information processing tasks, *information coordination tasks*, that require the combined performance of two or more components and a single coordinated response. We believe Yee et al.'s (1991) paradigm of concurrent processing and a coordinated response is more typical of many real world performances than the more common dual-task paradigm, which requires concurrent processing and independent responses. The present study is a further examination of issues related to performance in such information coordination tasks and builds on a series of previous studies in this area (Fischer, Hickey, Pellegrino, & Law, in press, Law, Pellegrino, Mitchell, Fischer, McDonald, & Hunt, in press; Morrin, Law, & Pellegrino, 1993; Pellegrino, Hunt, & Yee, 1989; Yee et al., 1991; Yee, Laden, & Hunt, 1991).

The particular focus of the present research is the effects of training on coordination task performance, including the changing relations with and among component abilities, and the mediating effects of task related covariates such as individual differences in verbal processing and working memory. In particular we are concerned with whether training on a component alone or training on a component in the context of the coordination task leads to superior performance. A related issue is whether different training procedures foster different strategies, thereby capitalizing on different ability profiles (e.g., Kyllonen, Lohman, & Snow, 1984). In establishing training procedures for occupations that require performance under attentional load (e.g., pilots and air-traffic controllers), considerations of working memory capacity and the mediating effects of other relevant covariates may make one training procedure especially preferable over the other.

A Model for Information Coordination Tasks

Within the model developed by Yee et al. (1991), coordination is a task in itself that requires a separate ability. For coordination to occur the component information must first be represented in a common propositional code. It is this requirement of a common code combined with parallel processing prior to serial recoding that gives coordination tasks a distinctive and often counterintuitive "compression effect" (i.e., the effect sizes of task relevant variables in the coordination task are compressed relative to the corresponding effect sizes in component tasks). Simple resource competition models (e.g., Hunt & Lansman, 1982; Kahneman, 1973) predict increased effect sizes in such situations, and therefore cannot explain the compression phenomenon. Although some complex resource models (e.g., Pashler, 1989) can account for compression-like effects in dual-task situations, these models do not explain compression in the single response situation. Nevertheless, compression effects are ubiquitous in coordination tasks. Accordingly, Yee et al. (1991) created a complex resource model that accounted for compression effects and evaluated it in a number of tasks involving the coordination of perceptual and verbal information. Subsequently, a number of studies have supported the existence of an independent ability to coordinate information both within and across cognitive domains (Law et al., in press; Morrin et al., 1993; Yee, Laden, & Hunt, 1991). Carlson, Khoo, Yaure, and Schneider (1990) have also suggested that the coordination of separate representations is a separable component in complex skills.

Training Effects

Previous research on part-whole task training (Fabiani, Buckley, Gratton, Coles, & Donchin, & Logie, 1989; Fredriksen, & White, 1989; Gopher, Weil, & Siegel, 1989) has supported the effectiveness of training that emphasizes selected components of a complex task. However, the same research has provided a mixed message regarding the relative effectiveness of training on components separately versus training on components in context. For example, comparing Fredriksen and White's (1989) method of separate component training with Gopher et al.'s (1989) method of training components in context, Fabiani et al. (1989) found that training on separate components led to higher levels of performance in the target task, but that training in context resulted in reduced interference during dual-task performance. Thus, training in context appears to foster processing that is more resource efficient, whereas training on separate components appears to produce superior performance in single task situations.

The present study involved training subjects on an arrival time-verbal coordination task. In this task, subjects are required to make a relative arrival time judgment and verify a sentence describing the event (e.g., "The white ship will not arrive after the black ship."). Thus, the task includes both dynamic spatial and verbal components. Furthermore, ideal performance requires satisfactory completion of both components and effective coordination of the resultant information. That the coordination task requires an independent ability to coordinate information is demonstrated by the existence of *reliable* coordination task variance that cannot be explained by the component tasks. This demonstrates that performance in the coordination task relies on individual differences separate from those employed in the component tasks. Previously, a confirmatory factor analysis (Morrin et al., 1993) supported such a coordination task model in the arrival time-verbal coordination task.

In the training phase of the present study subjects received practice and feedback that focused on the relative arrival time component. One group of subjects received feedback in the context of the coordination task, whereas a second group received feedback on the arrival time component alone. Subjects were first pretested for working memory capacity, sensitivity to relative velocity, and verbal processing ability. Before and after training, subjects in both groups performed the arrival time component, verbal component, and arrival time-verbal coordination tasks. Thus, the design allowed for an examination of changes in performance due to training, the changing relations among the tasks, and the mediating effects of selected covariates. If the findings of Fabiani et al. (1989) generalize to the current coordination task, we should expect higher levels of performance in the group that was trained on the component alone and decreased dependence on working memory in the context trained group.

Component Abilities, Task Performance & Training

Ackerman (1988, 1992) described a theory of changing ability-performance relationships that occur during skill acquisition as a function of three task characteristics: a) degree of practice; b) consistency of information processing demands; and c) task complexity. The theory combined a three phase theory of skill acquisition based on Posner and Fitts (1967) with a hierarchical model of cognitive/intellectual abilities (Marshalek, Lohman, & Snow, 1983). Early in skill acquisition, performance is dominated by general cognitive abilities such as working memory and broad area abilities such as spatial and verbal abilities, dependent upon the content of the task. During this phase, called the cognitive phase, the learner develops an understanding of task goals and formulates strategies to deal with task demands. The second or associative phase involves the proceduralization (Anderson, 1983) or strengthening (Posner & Fitts, 1967) of strategies and is highly influenced by perceptual speed. The third and final autonomous phase involves the automatization of task skills as described by Shiffrin and Schneider (1977; Schneider & Shiffrin, 1977) and is dominated by psychomotor speed.

The progression through the phases of skill acquisition is dependent on consistent information processing demands (i.e., the consistent mapping of stimulus response relationships or the consistency of information within different stages of a given task, see e.g., Carlson & Lundy, 1992; Fisk, Oransky, & Skedsvold, 1988; Schneider, Dumais, & Shiffrin, 1984). Tasks that are dominated by inconsistent information processing demands remain highly dependent on general cognitive and broad area abilities. Similarly, the higher the complexity of the task, the greater the dependence on general cognitive abilities. Thus, to the extent that our training procedures provide consistent information processing demands, Ackerman's (1988) theory predicts diminishing dependence on working memory and component abilities as subjects progress through the phases of skill acquisition.

In addition to evaluating the changing relations of working memory capacity and performance over the course of training, we were also interested in working memory's potential to account for the ability to coordinate information. According to Baddeley (1986, p. 34) "Working memory implies a system for the temporary holding and manipulation of information...it enables otherwise independent information to interact." By definition all coordination tasks require the concurrent maintenance, transformation, and integration of independent information. Thus, Baddeley's description of working memory is consistent with a system capable of the processing needed in coordination tasks. Accordingly, individual differences in working memory may account for all or part of the variance corresponding to information coordination ability. To assess this possibility, we examined the relationship of working memory capacity and coordination task performance after controlling for independent performance in the component tasks. Positive findings regarding the relationship of working memory capacity and the ability to coordinate information could prove fruitful for both research paradigms. In particular, the investigation of coordination tasks (Yee et al., 1991) has been focused on the the integrative and decisional processes that correspond to working memory's executive processes, an area which Baddeley (1986, p. 225) has called the "Area of residual ignorance within the working memory model." Thus, a full understanding of the relationship of working memory capacity and information coordination ability may illuminate an area of the working memory model that until now has remained unexplored.

Finally, Law et al. (in press) found that the relative arrival time task, a component in the arrival time-verbal coordination task, is itself a coordination task, involving the coordination of relative velocity and distance information. Thus, the arrival time task requires the coordination of dynamic spatial information, whereas the arrival time-verbal task requires coordination across the dynamic spatial and verbal domains. Law et al. (in press) also found that most subjects exhibit a distance bias in relative arrival time judgments, weighting relative distance information over relative velocity information.[1] Thus, one indication of an individual's ability to coordinate dynamic spatial information is the extent to which relative velocity and distance information are integrated in arrival time judgments. Subsequent research indicated that training with explicit feedback caused most subjects to represent both sources of information more fully, though not ideally (Fischer et al., in press). Fischer et al. (in press) also found that sensitivity to relative velocity information mediated the effect of training in the arrival time task. Additionally, a number of studies have found gender differences in both relative arrival time and velocity judgments with males performing at higher levels than females (Hunt, Pellegrino, Frick, Farr, & Alderton, 1988; Law, Pellegrino, & Hunt, 1993; Law et al., press; Morrin et al., 1993). Accordingly, we performed two analyses on posttest performance in the arrival time and arrival time-verbal coordination tasks: one to determine if gender, sensitivity to relative velocity, working memory capacity, and verbal processing ability influenced which subjects came to coordinate dynamic spatial information in the component task, and the second to determine the importance of the same predictors, when the judgments were performed under the added cognitive load of the coordination task.

Method

Subjects

A total of eighty subjects were tested, with one half of the subjects (20 males, 20 females) assigned to each treatment group. The subjects were solicited from the campus community of Vanderbilt University and were paid $60 for completing six testing sessions. During the analysis it was determined that several subjects had misunderstood the instructions on one or more tasks. Several subjects' data were also lost due to computer/human error. Finally, due to the combination of very fast response times and very low accuracy scores two subjects were deemed not to have given their full cooperation on one or more tasks. Only subjects with complete and satisfactory data were used in the analyses. In all, there were 33 subjects in the context training group and 35 subjects in the component training group.

Materials

All subjects initially participated in a session that included measures of verbal processing ability, sensitivity to relative velocity, and working memory capacity. All subjects also participated in pre and posttreatment sessions that included the arrival time-verbal coordination, arrival time component, and verbal component tasks. During three training sessions one treatment group practiced and received explicit feedback in the arrival time component task. The other treatment group practiced the arrival time-verbal coordination task, while receiving explicit feedback focused on the arrival time component. All of the measures were computer administered, stimuli were presented randomly within the balancing constraints of each task, and responses were recorded via a standard computer keyboard. In each task subjects were instructed to perform as accurately as possible and then as quickly as possible. The specifics of each task are presented below.

Relative Velocity Task. In each trial subjects viewed two objects, the figures 1 and 0, in a dynamic display. The objects moved at either a 1.5:1 or 2:1

relative velocity ratio (i.e., one object moved either 50% or 100% faster than the other) and followed one of the three stimulus configurations defined by the path relationships depicted in the top panel of Figure 1. The subjects' task was to indicate which of the objects was moving faster. Velocity ratio, stimulus configuration, and faster object (1 or 0) were fully crossed and the design replicated 12 times for a total of 144 trials.

Verbal Processing Task. The verbal processing task was based on the sentence verification paradigm developed by Clark & Chase (1972). In this task, verbal statements with varying degrees of syntactic complexity were compared with a static visual display of a 1 either above or below a 0. Eight possible verbal descriptions (e.g., The 1 is not above the 0) were created by varying negative vs. affirmative statements, linguistically marked vs. unmarked adjectives (e.g., "above" vs. "below"), and true vs. false descriptions. The subjects' task was to indicate whether the sentence truly described the digit configuration. In all there were 16 trials for each verbal description for a total of 128 trials.

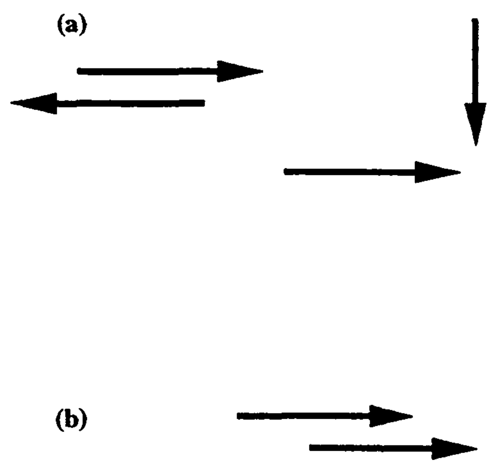

Figure 1. Arrows indicate the relative directions of motion in (a) the relative velocity, arrival time component, and arrival time-verbal coordination tasks; and (b) in the verbal component task.

Working Memory Battery

Working memory capacity was assessed using a subset of a working memory task battery (Battery CA4P) developed as part of the Learning Abilities and Measurement Program at the Air Force Human Resource Laboratory, Brooks Air Force Base, Texas. In each case, the tasks were designed to adhere to Baddeley's (1986) criteria for working memory tasks, requiring the simultaneous processing and storage of information. Each of the tasks were preceded by practice items and measures of processing speed that employed single components of the more complex working memory tasks. The selection of tasks was balanced to include analogous measures with verbal and spatial content.

Four-Term Ordering. In the verbal task, subjects attempted to relate the information from three separately presented sentences to the order of four key words presented later (see Figure 2). Two sentences described the order of the key words (e.g., chair and lamp; or bird and cow) and a third sentence described the sequence of the other two sentences using category names (e.g., FURNITURE or ANIMALS). The four key words were in a different color than the rest of the sentence, and this color matched the color of the appropriate category name (e.g., FURNITURE, chair, and lamp were blue; ANIMALS, bird, and cow were pink). The subjects' objective was to determine the correct sequence of the four key words. The three sentences were presented individually in a random order. After the third sentence was presented, a screen containing the eight possible orderings appeared. Subjects were allowed 15 seconds counted by an onscreen timer to determine the correct order. After each trial correct/incorrect feedback was given, and in the case of incorrect answers, subjects could view the three statements and the eight possible answers for as long as they wished. A total of 24 trials were administered.

1 The **FURNITURE** does not come before the ***ANIMALS***.

2 The ***BIRD*** comes after the ***COW***.

3 The **LAMP** does not come after the **CHAIR**.

Correct Choice: ***COW, BIRD***, **LAMP, CHAIR.**

Figure 2. Stimuli in a single trial of the verbal four-term ordering task.

In the spatial task, subjects attempted to relate three individually presented pictorial statements to the relative positions of four colored block figures (see Figure 3). In two of the statements, two blocks appeared with each block divided by a diagonal line and the colors pink and black or blue and black above and below the diagonal. Within these statements both blocks were either pink with black or blue with black. The direction of the diagonal line could change positions (i.e., from top left to bottom right or from bottom left to top right), giving different blocks different configurations. The blocks were related by an arrow indicating the relative position of the two blocks (i.e., one block above or below the other). The arrow could also have a slash through it indicating a 'not' relationship. A third statement contained a single pink block and a single blue block related by an arrow statement (i.e., one color block to the right or left of the other). Within a trial the three statements appeared individually and in a random order. After viewing the statements, subjects were given eight seconds counted by an onscreen timer to choose from the eight possible combinations. Correct/incorrect feedback was given after each trial, and for incorrect answers subjects were allowed to review the three statements and eight possible answers for as long as they wished. A total of 24 trials were administered.

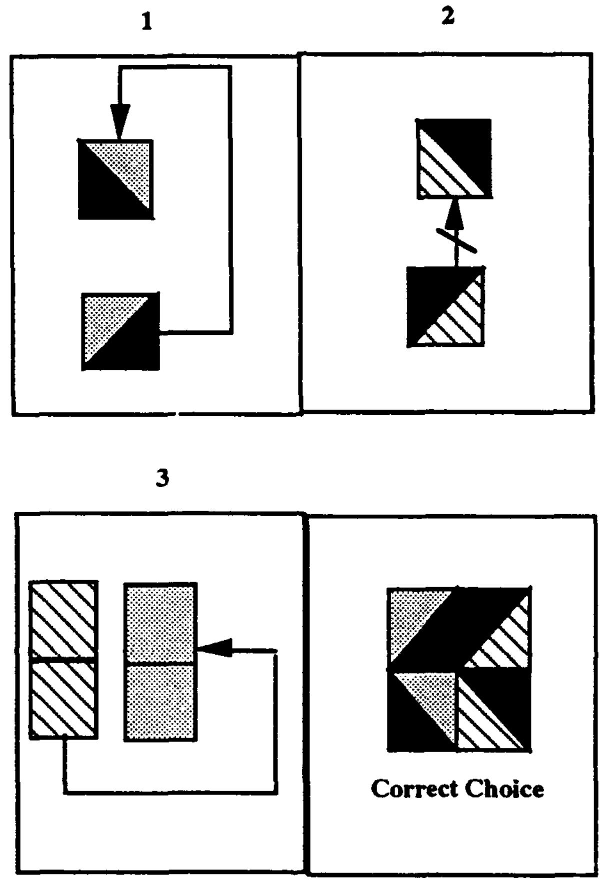

Figure 3. Stimuli in a single trial of the spatial four-term ordering task.

Verification Span. In the verbal task (see Figure 4), subjects attempted to memorize lists of three to five individually presented words. Between word presentations, subjects verified whether a sentence was factual or nonsensical. Subjects were allowed eight seconds to verify each sentence with an onscreen timer counting the seconds. If the subjects were incorrect regarding the sentence verification, they were prompted to be more careful. Following the presentation of a three to five word sentence pairs, subjects attempted to recall the words in order by typing the first two letters of each word at a prompt. Feedback was given for both the number of correct verifications and the number of words recalled in the correct order. In total, 48 words and 48 fact verifications were administered.

In the spatial task, subjects attempted to memorize three to five individually presented 3 x 3 matrices that had one of nine squares shaded (see Figure 5). Between individual matrix presentations, subjects verified an addition equation in which two line matrices were to be added together to form a third line matrix (e.g., Matrix 1 + Matrix 2 = Matrix 3). Each line matrix consisted of a 3 x 3 dot matrix with a line connecting the dots in a variety of configurations. Subjects were allowed eight seconds to verify each addition with an onscreen timer counting the seconds. If the subjects were incorrect regarding the equation verifications, they were prompted to be more careful. Following the presentation of a complete set of three to five matrix and verification pairs, a 3 x 3 cell matrix with cells numbered one to nine was presented and subjects responded by typing the numbers corresponding to the shaded squares in the order of their presentation. To prevent a simple number recall strategy, the numbered cells in a recall matrix maintained a left to right order within a row, but the horizontal ordering of the rows varied randomly over trials (e.g., Row 1 = 4, 5, 6; Row 2 = 1, 2, 3; Row 3 = 7, 8, 9). Feedback was given for the number of correct verifications and squares recalled in the correct order. In total, 48 matrices and 48 matrix additions were administered.

1 **BUILDING**

VERIFY: A bear is an animal that lives in a forrest. (T or F)?

2 **WARRIOR**

VERIFY: A knife is cutlery that is kept sharp. (T or F)?

3 **RADIO**

VERIFY: An oak is a creature that eats mice. (T or F)?

Correct Recall: BU, WA, RA

Figure 4. Stimuli in a single trial of the verbal verification span task.

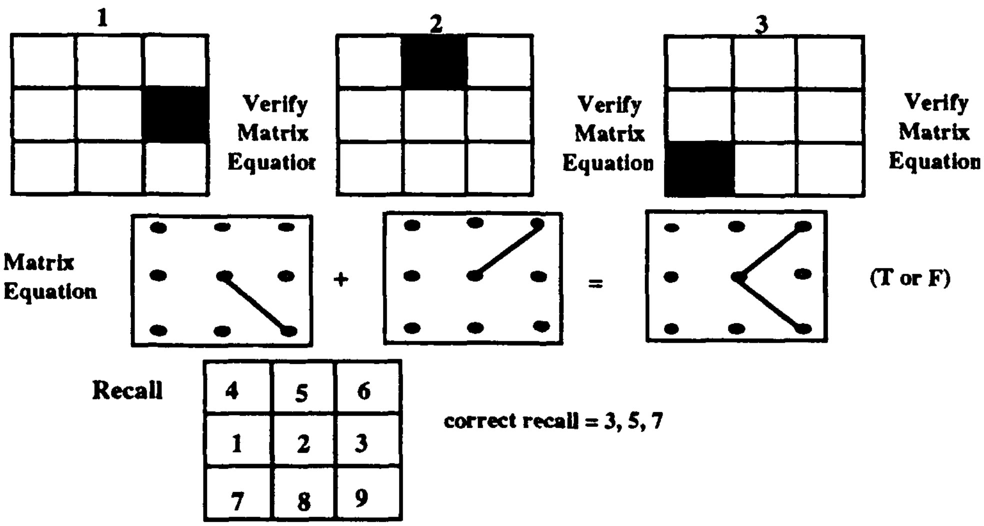

Figure 5. Stimuli in a single trial of the spatial verification span task.

Arrival Time-Verbal Coordination Battery

Arrival Time Component Task. Except for the addition of "+" shaped targets, the display in this task was identical to the relative velocity task display. In each trial subjects observed the figures 1 and 0 moving towards a + shaped target or targets. One object, the winner, would have reached its target first when the objects completed their trajectories. However, the display terminated when the winner completed two-thirds of the overall start to target distance. The subjects' task was to indicate which object was the winner. The actual arrival time differential (ATD) between the objects was either 500 or 1000 ms. Throughout each trial the slower object was always closer to its target. However, trials were balanced so that the faster object would overcome the closer object in 50% of the trials and the closer object would have won the remaining 50%. These trials were called the faster and closer trials, respectively. Thus, the trial structure allowed for the assessment of the relative contribution of velocity and distance information in each subject's decisions. ATD, velocity ratio, Faster/closer trials, and configuration were fully crossed and the design replicated 6 times for a total of 144 trials.

Verbal Component Task. The verbal processing component was identical to the verbal component used by Morrin et al. (1993). This task was analogous to the static verbal processing task with the exception that the statements referred to arrival time information that was made "trivial" through the combination of parallel path relationships (see bottom panel of Figure 1) and a 1:1 relative velocity ratio. Thus, subjects needed only to make simple distance observations, as the closer object always won. Once again eight possible verbal descriptions were created by crossing negative vs. affirmative statements, marked vs. unmarked adverbs, and true vs. false descriptions. A total of 96 trials, 12 for each statement type were administered.

Arrival Time-Verbal Coordination Task. The arrival time-verbal coordination task was identical to the task used by Morrin et al. (1993). The task was created by crossing the arrival time component task variables of relative velocity ratio, ATD, stimulus configuration, and faster/closer with the eight verbal descriptions from the verbal component task. The subjects' task was to judge whether the verbal information truly described the dynamic spatial event. In contrast to the verbal component task, where the dynamic spatial judgment was trivial, both sources of information were presented over the full range of difficulty levels. A total of 384 trials were administered, two for each unique trial type.

Training Sessions. In the training sessions the context treatment group performed relative arrival time judgments in the context of the arrival time-verbal coordination task and received feedback regarding arrival time judgments, whereas the component treatment group performed relative arrival time judgments and received feedback pertaining to those judgments. After each trial subjects in both groups were given correct/incorrect feedback and additional information describing the variables critical to the arrival time judgment. For example:

WRONG
Although the one was traveling 2 times as fast as the zero
the zero would have arrived 1/2 second before the one
Please, press <Enter> to continue

After each block of 96 trials subjects were given the running averages of their response accuracy and latency. Both groups performed 384 trials during each training session.

Apparatus

The relative velocity, verbal processing, and working memory tasks were administered on IBM personal computers equipped with EGA color monitors running in high resolution mode. The arrival time-verbal coordination battery was administered on IBM compatible computers equipped with CGA color monitors running in high resolution mode.

Design and Procedure

In all, subjects completed six testing sessions. The working memory, relative velocity, and verbal processing tasks were administered in a two hour session on Friday of the week prior to the pretest, training, and posttest sessions. The working memory tasks were given first followed by the relative velocity and verbal processing tasks. Within the working memory battery, the order of presentation was four-term ordering (verbal), verification span (verbal), four-term ordering (spatial), and verification span (spatial). All subjects returned on Monday of the following week, when they were pretested on the arrival time component, verbal component, and arrival time-verbal coordination tasks in a 90 minute session. The order of pretest administration was balanced using a three order Latin Square. Following the pretest session, three separate training sessions were conducted on Tuesday, Wednesday, and Thursday. Training sessions lasted approximately 60 minutes. In the posttest session, which was conducted on Friday, subjects performed the two component tasks and the coordination task, all without feedback. Once again, the order of task administration was determined by a Latin Square without replicating the order in the pretest session.

Results and Discussion

Overview

There are two major sections that form the basis for our presentation of results and discussion. In the first section we focus on the effects of the different experimental variables within each of the pre, post, and training session tasks. These analyses concentrate on which variables exhibited significant effects on latency and accuracy of performance within each task. In the second section we shift from group level data and analyses to a focus on issues of individual differences, particularly, how various subject characteristics such as verbal and spatial ability and working memory capacity relate to performance in the pre, post and training session tasks. These analyses concentrate on explicating correlational patterns exhibited within and across the different training conditions.

Within Task Variable and Training Effects

These analyses concern performance in the arrival time-verbal coordination task battery. The primary objectives were to assess the group effects of treatment condition and gender and to verify that internal task variables affected performance consistent with expectations derived from our prior research. A separate mixed model analysis of variance (ANOVA) was conducted for the accuracy and latency (correct trials only) data in each task. Each of the ANOVA designs crossed the between subject factors of training condition and gender with the pre and post training scores of all the variables in a task, except that the arrival time and coordination task analyses did not include configuration and the coordination task analysis did not include the faster/closer variable. Thus, the arrival time component task design was: treatment x gender x pre/post x ATD x velocity ratio x faster/closer. The verbal component task design was: treatment x gender x pre/post x markedness x affirmation x true/false. And the coordination task design combined the two other task designs but dropped the faster/closer variable.

The data from the feedback/training days were analyzed separately for the two treatment groups, replacing the pre/post variable with day (1, 2, 3) and using the arrival time or coordination task designs for the component and context training groups, respectively. Because of the combined size and statistical power of the designs employed, within subject effects were evaluated at $p < .01$. Furthermore, the analyses were carried only to the depth of two-way interactions with the remaining variance returned to the residual. Between subject effects were evaluated at the traditional $p < .05$.

In general the ANOVA results supported the validity of the variable manipulations within each of the experimental tasks. The ATD and faster/closer variables were major determinants of performance in the arrival time task and the affirmation-negation variable affected performance in the verbal task. Together, the effects of ATD and affirmation affected performance in the coordination task. Further, there were significant accuracy gains in all three tasks following training. However, latency improved only in the verbal task.

The compression effect pattern described by Yee et al. (1991) was observed for both the dynamic spatial and verbal pretraining data. However in the posttraining data, compression was observed only for the verbal variable. The reason for the lack of compression in the posttraining spatial variable is not entirely clear. However, it appears to be related to differential training effects in the component and coordination tasks.

Arrival Time Component Task. Means and standard deviations corresponding to the within subject effects are presented in Table 1. Test statistics corresponding to statistically significant effects are presented in Table 2. As expected, subjects were both more accurate and responded faster in the 1000 ms ATD trials. Similarly, subjects were more accurate and responded faster in the closer trials. In the latency data there was also a significant effect of relative velocity. Although the main effect of relative velocity was not significant in the accuracy data, it is interesting that the shorter latencies were associated with the more difficult 2:1 relative velocity condition. This suggests that subjects may have set an early decision deadline in the more difficult condition.

In the accuracy data there were two significant interactions, relative velocity with the faster/closer trials and relative velocity with ATD. The cell means of these interactions are presented in Figure 6. As can be seen in the upper panel of Figure 6, the effect of relative velocity was disordinal within the faster/closer trials with higher performance in the 1.5:1 velocity ratio-faster trials and in the 2:1 velocity ratio-closer trials. A simple effects analysis indicated that the effect of velocity ratio was significant in both the faster and closer trials, $F(1, 64) = 56.29$, and $F(1, 64) = 63.50$ (p's $< .001$), respectively. The interaction is consistent with the bias observed by Law et al. (in press). That is, even though an unbiased estimate of arrival time would be independent of relative velocity, relative distance, and the faster/closer variable, subjects were more accurate when the distance differential was greater for a winning object that was leading (2:1, closer trials) and when the distance differential was lesser for a winning object that was trailing (1.5:1 faster trials). In the relative velocity ATD interaction shown in the lower panel of Figure 6, simple effects indicated that the effect of relative velocity was significant only in the 1000 ms ATD trials, $F(1, 64) = 64.96$, $p < .001$. The lack of an effect of relative velocity across ATD is consistent with the finding that the disordinal faster/closer by relative velocity interaction prohibited a significant main effect of relative velocity.

In the latency data there were also two significant interactions, faster/closer with ATD and faster/closer with pre/post. A simple effects analysis of the faster/closer ATD interaction indicated that the effect of ATD was significant only in the closer trials, $F(1, 64) = 13.55$, $p < 001$. As can be seen in the top panel of Figure 7, the mean response latency in the 1000 msec faster trials approached that of the more difficult 500 msec faster trials. Thus, the interaction was indicative of greater difficulty in the faster trials. The cell means corresponding to the faster/closer pre/post interaction are presented in the bottom panel of Figure 7. In this case, a simple effects analysis indicated that the effect of the faster/closer trials was significant only in the pretest session, $F(1, 64) = 51.41$, $p < .001$. In the posttest session the latencies of the two trial types had converged with latency increasing in the closer trials and decreasing in the faster trials.

Overall, response accuracy improved significantly from the pre to posttest sessions. However a similar effect of testing session was not apparent in the latency data. It appears that the lack of a pre/posttest latency effect resulted from the differential effects of training on faster and closer trials. More important for the present study, there were no significant main effects or interactions associated with the component and contextual treatments. Thus, the accuracy of subjects' performance increased equally, regardless of the training they received.

Regarding gender, males were more accurate ($M = 68.30\%$) than females ($M = 63.37\%$), however females ($M = 3020$ ms) responded more quickly than males ($M = 3376$ ms). Together these findings suggest that female subjects responded more quickly based on less information. This is similar to the relative velocity latency effect noted above. Both are consistent with previous findings that relative velocity information becomes resource-limited in the process of making relative arrival time judgments (Law et al., in press) and that males are more sensitive to relative velocity information (Law et al., 1993). Thus, it appears that resource limitations and the degradation of relative velocity information caused most subjects to respond early in the more difficult trials and some females to set an earlier deadline than most males.

Table 1

Arrival Time Component Task Within Subject Means (Standard Deviations): Percent Correct and Latency(msec).

	Accuracy	Latency
	Pretest Session	
ATD(msec):		
500	59.37 (25.57)	3257 (817)
1000	64.29 (23.01)	3171 (840)
Velocity Ratio:		
1.5:1	63.03 (23.33)	3309 (754)
2:1	62.46 (29.51)	3119 (889)
Faster Trials	49.90 (21.43)	3379 (854)
Closer Trials	75.59 (25.00)	3049 (770)
	Posttest Session	
ATD(msec):		
500	64.29 (23.01)	3197 (795)
1000	73.85 (21.74)	3188 (740)
Velocity Ratio:		
1.5:1	70.16 (19.81)	3214 (748)
2:1	67.99 (25.56)	3172 (787)
Faster Trials	59.82 (22.01)	3222 (779)
Closer Trials	78.33 (19.79)	3164 (756)

Table 2

Statistically Significant Effects in the Arrival Time Component Task.

	Accuracy
Gender:	$F(1, 65) = 16.47, p < .001$
ATD:	$F(1, 65) = 178.79, p < .001$
Faster/Closer:	$F(1, 65) = 57.92, p < .001$
Pre/Post:	$F(1, 65) = 66.74, p < .001$
Faster/Closer X Velocity Ratio:	$F(1, 65) = 158.16, p < .001$
ATD X Velocity Ratio:	$F(1, 65) = 9.32, p < .01$
	Latency
Gender:	$F(1, 65) = 6.20, p < .05$
ATD:	$F(1, 65) = 7.94, p < .01$
Faster/Closer:	$F(1, 65) = 27.57, p < .001$
Velocity Ratio:	$F(1, 65) = 14.12, p < .001$
Faster/Closer X ATD:	$F(1, 65) = 7.23, p < .01$
Faster/Closer X Prepost:	$F(1, 65) = 12.38, p < .001$

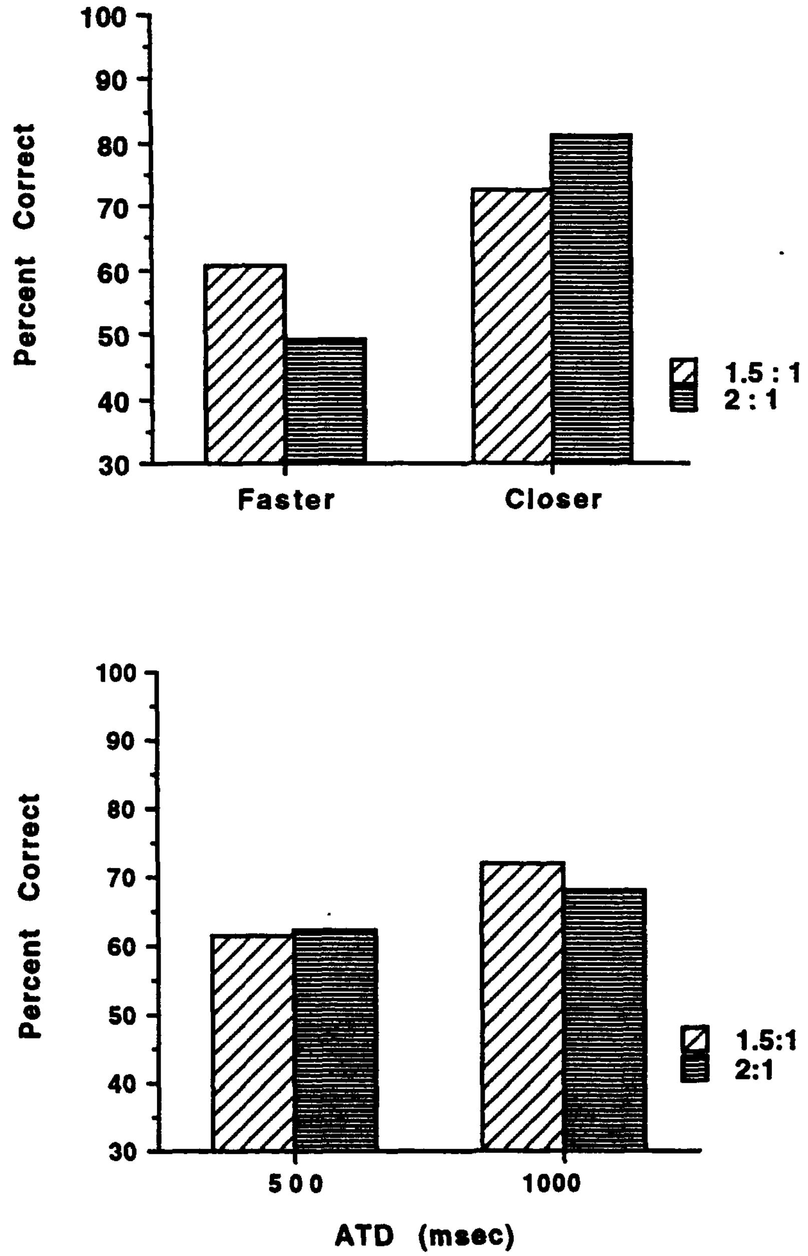

Figure 6. Arrival time component task accuracy cell means: relative velocity by faster/closer (top panel) and relative velocity by ATD (bottom panel).

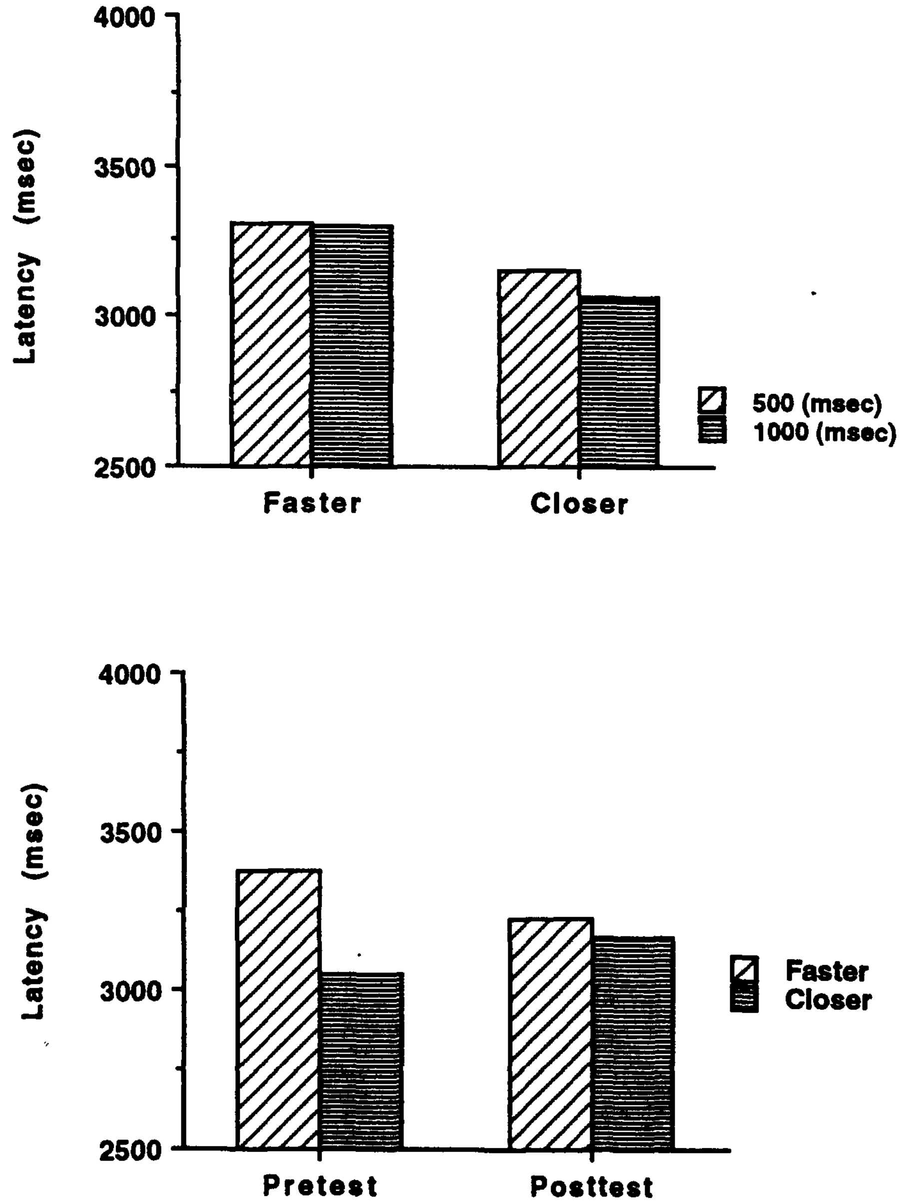

Figure 7. Arrival time component task latency cell means: ATD by faster/closer (top panel) and faster/closer by pre/posttest (bottom panel).

Verbal Component Task. Means and standard deviations corresponding to the within subject effects are presented in Table 3. Test statistics corresponding to statistically significant effects are presented in Table 4. As expected, subjects were more accurate and responded faster in the affirmative trials. From pretest to posttest overall performance became more accurate and latency decreased. In the accuracy data there were two significant two-way interactions, pre/post with affirmation and markedness with true/false. The cell means corresponding to the interactions are presented in the top and center panels of Figure 8, respectively. A simple effects analysis of the pre/post affirmation interaction indicated that performance in the negative trials was significantly affected by training , $F(1, 64) = 25.46$, $p < .001$, whereas the effect was nonsignificant in the affirmative trials. As can be seen in Figure 8, this interaction resulted from a near ceiling effect in the affirmative condition.

In the markedness true/false interaction, true/false statements significantly affected accuracy in the marked condition, $F(1, 64) = 13.96$, $p < .001$, but not in the unmarked condition. Interestingly, accuracy was lower in the true condition than the false condition. Although this may not be an intuitive outcome, it is consistent with previous sentence picture verification research (see, e.g., Clark & Chase, 1972; Table 5, p. 492). Thus, the interaction suggests an interference effect related to true responses and the recoding of marked adjectives.

There was also a significant two-way interaction in the latency data, affirmation with true/false. The interaction is depicted in the bottom panel of Figure 8. In this case a simple effects analysis indicated that the effect of true false was significant in the affirmative condition, $F(1, 64) = 32.24$, $p < .001$, and not significant in the negative condition. This suggests that subjects approached an internal decision deadline in the negative condition. Finally there were no main effects or interactions associated with training condition in either the latency or accuracy data.

Table 3

Verbal Component Task Within Subject Means (SD): Percent Correct and Latency(msec).

	Accuracy	Latency
	Pretest Session	
Affirmative:	94.71 (8.55)	1942 (524)
Negative:	87.63 (12.95)	2439 (612)
Marked:	90.57 (11.85)	2210 (622)
Unmarked:	91.76 (11.17)	2171 (620)
True:	90.38 (12.02)	2172 (642)
False:	91.95 (10.96)	2209 (600)
	Posttest Session	
Affirmative:	96.48 (6.33)	1618 (599)
Negative:	93.14 (8.94)	2015 (633)
Marked:	94.70 (8.02)	1827 (652)
Unmarked:	94.92 (7.82)	1806 (643)
True:	94.64 (8.17)	1790 (667)
False:	94.98 (7.66)	1843 (627)

Table 4

Statistically Significant Effects in the Verbal Component Task.

	Accuracy
Affirmation:	$F(1, 65) = 65.82, p < .001$
Pre/post:	$F(1, 65) = 21.61, p <$ 001
Affirmation X Day:	$F(1, 65) = 15.11, p < .001$
Markedness X True/False:	$F(1, 65) = 10.90, p < .01$
	Latency
Affirmation:	$F(1, 65) = 252.72, p < .001$
Pre/post:	$F(1, 65) = 43.21, p < .001$
Affirmation X True/False:	$F(1, 65) = 30.59, p < .001$

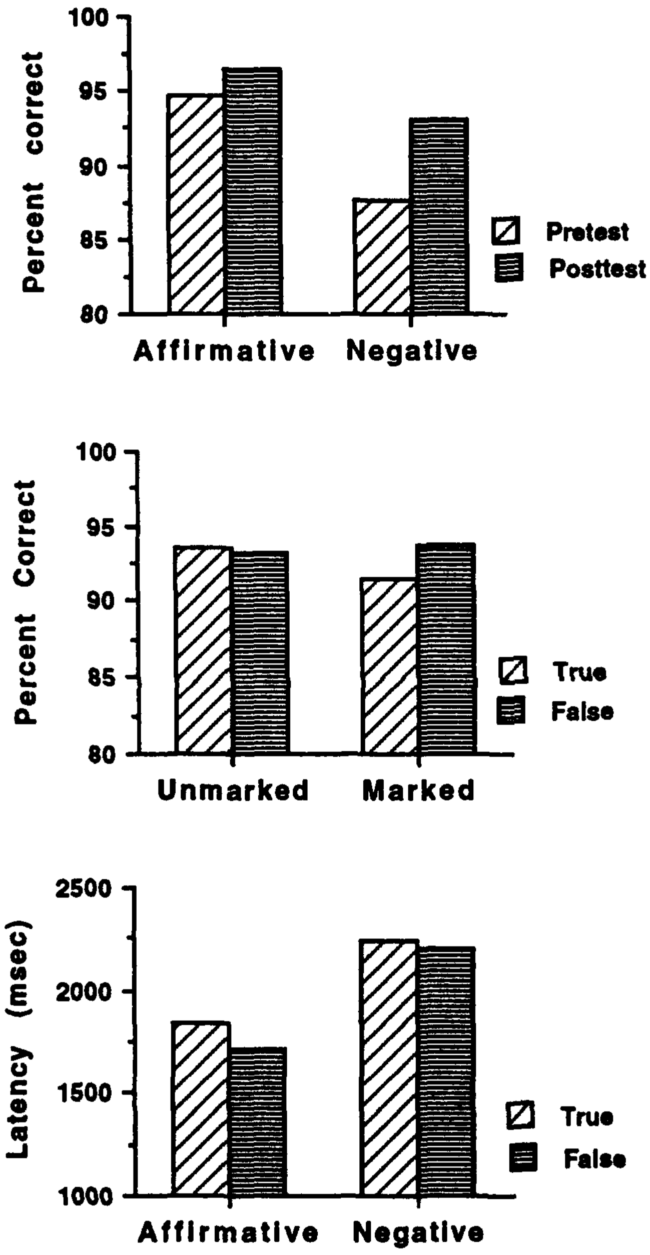

Figure 8. Verbal component task cell means: pre/posttest by affirmative/negative accuracy (top panel), true/false by marked/unmarked accuracy (middle panel), and true/false by affirmative/negative latency (bottom panel).

Arrival Time-Verbal Coordination Task. Means and standard deviations corresponding to the within subject effects are presented in Tables 5 and 6 for the accuracy and latency data, respectively. Test statistics corresponding to statistically significant effects are presented in Table 7. As in the arrival time and verbal tasks, subjects were more accurate and responded faster in both the 1000 msec ATD and affirmative trials. Consistent with results obtained in the arrival time task, accuracy improved from pretest to posttest without a concurrent improvement in latency. This suggests that overall latency in the coordination task is determined by the arrival time component and not the verbal component, which evidenced reduced latency in the posttest session. Nevertheless, latency was significantly affected by relative velocity, markedness, and true/false statements. As in the arrival time task, the effect of relative velocity was that shorter response times occurred in the lower accuracy condition. Furthermore, that the relative velocity effect size increased under the higher cognitive load of the coordination task offers additional support for the hypothesis that the effect of relative velocity is associated with resource limitations on the processing of relative velocity information.

In addition, there were four significant interactions affecting accuracy, relative velocity with pre/post, relative velocity with affirmation, ATD with pre/post, and affirmation with true/false, and four significant interactions affecting latency, ATD with pre/post, relative velocity with true/false, affirmation with markedness, and affirmation with pre/post. Regarding the accuracy interactions, a simple effects analysis indicated that relative velocity accounted for small but significant effects in the pretest and affirmative conditions, but not in the posttest and negative conditions. Similarly, the affirmation with true/false interaction represented a significant effect of affirmation in the false trials and the lack of an effect in the true trials.

The ATD pre/post interactions are presented in Figure 9. The effect of ATD on accuracy was significant across testing sessions, but there were greater posttest gains in the easier 1000 msec trials as can be seen in the top panel of Figure 9. The latency interaction shown in the bottom panel of Figure 9 reflected a small but significant pretest to posttest latency decrease in the easier 1000 msec trials and no change in the 500 msec trials. The cell means corresponding to the remaining latency interactions are presented in Figure 10. A simple effects analysis indicated that the true/false with velocity ratio interaction represented a small but significant effect of the true/false variable in the 1.5:1 condition and no difference in the 2:1 condition. A simple effects analysis indicated that the effect of markedness was highly significant in the affirmative condition and attenuated in the negative condition. Similarly, the effect of affirmation was highly significant in the pretest and attenuated in the posttest trials. None of these interactions seriously qualify the basic findings that subjects responded faster and more accurately in the 1000 ATD and affirmative trials.

As in the arrival time task, males (M = 65.84%; M = 3486 msec) were more accurate and slower than females (M = 63.13%; M = 3201 msec). Finally, there were no significant effects in either the latency or the accuracy data associated with the contextual or componential treatments. Thus, in terms of mean differences in the arrival time and coordination tasks it does not seem to matter whether one is trained in context or on separate components of a complex task.

Table 5

Coordination Task Within Subject Accuracy Means(Standard Deviations).

	Pretest Session	Posttest Session
500 msec ATD:	56.14 (14.79)	62.82 (15.32)
1000 msec ATD:	64.68 (15.12)	74.56 (15.12)
1.5:1 Velocity Ratio:	61.78 (15.97)	68.69 (15.82)
2:1 Velocity Ratio:	59.04 (15.00)	68.60 (16.42)
Affirmative:	61.30 (15.45)	69.29 (16.73)
Negative:	59.53 (15.61)	68.00 (15.46)
Marked:	59.57 (15.82)	68.61 (16.13)
Unmarked:	61.25 (15.23)	68.67 (16.11)
True:	60.06 (15.35)	68.98 (16.13)
False:	60.76 (15.75)	68.31 (16.11)

Table 6

Coordination Task Within Subject Latency Means(Standard Deviations).

	Pretest Session	Posttest Session
500 msec ATD:	3393 (745)	3384 (691)
1000 msec ATD:	3361 (699)	3253 (651)
1.5:1 Velocity Ratio:	3469 (723)	3438 (674)
2:1 Velocity Ratio:	3286 (710)	3199 (652)
Affirmative:	3194 (683)	3215 (663)
Negative:	3560 (714)	3422 (669)
Marked:	3448 (699)	3378 (665)
Unmarked:	3307 (724)	3259 (677)
True:	3356 (712)	3301 (667)
False:	3398 (732)	3336 (681)

Table 7

Statistically Significant Effects in the Arrival Time-Verbal Coordination Task.

	Accuracy
Gender:	$F(1, 65) = 5.36, p < .05$
ATD:	$F(1, 65) = 393.16, p < .001$
Affirmation:	$F(1, 65) = 9.39, p < .01$
Pre/post:	$F(1, 65) = 133.34, p < .001$
ATD X Pre/Post:	$F(1, 65) = 19.10, p < .001$
Velocity Ratio X Pre/Post:	$F(1, 65) = 8.46, p < .01$
Affirmation X Velocity Ratio:	$F(1, 65) = 9.78, p < .01$
Affirmation X True/False:	$F(1, 65) = 20.95, p < .001$
	Latency
Gender:	$F(1, 65) = 5.71, p < .05$
ATD:	$F(1, 65) = 59.06, p < .001$
Velocity Ratio:	$F(1, 65) = 165.12, p < .001$
Affirmation:	$F(1, 65) = 137.98, p < .001$
Markedness:	$F(1, 65) = 64.06, p < .001$
True/False:	$F(1, 65) = 7.12, p < .01$
ATD X Pre/post:	$F(1, 65) = 36.69, p < .001$
Velocity Ratio X True/False:	$F(1, 65) = 19.11, p < .001$
Affirmation X Markedness:	$F(1, 65) = 14.45, p < .001$
Affirmation X Pre/Post:	$F(1, 65) = 38.14, p < .001$

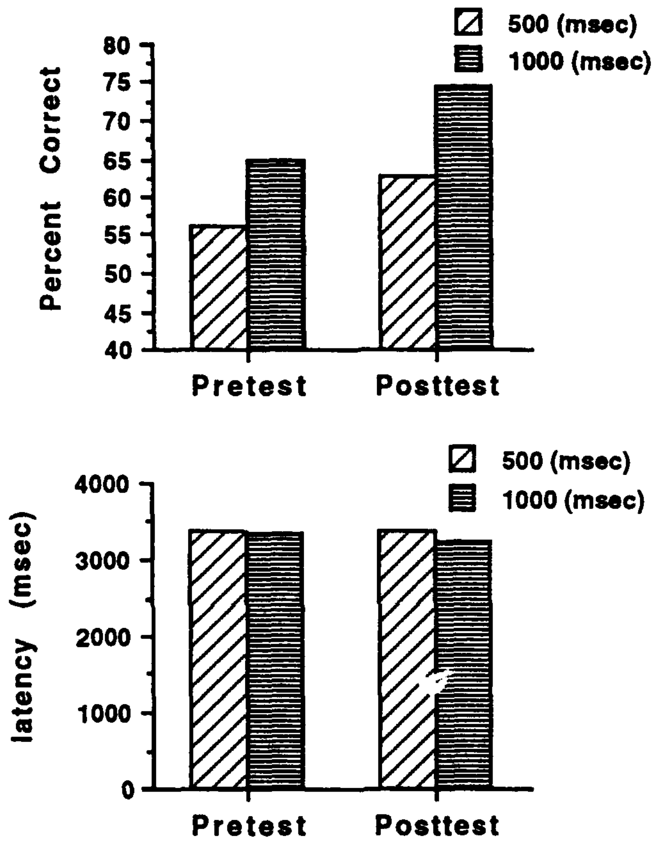

Figure 9. Coordination task cell means: ATD by pre/posttest accuracy (top panel) and latency (bottom panel).

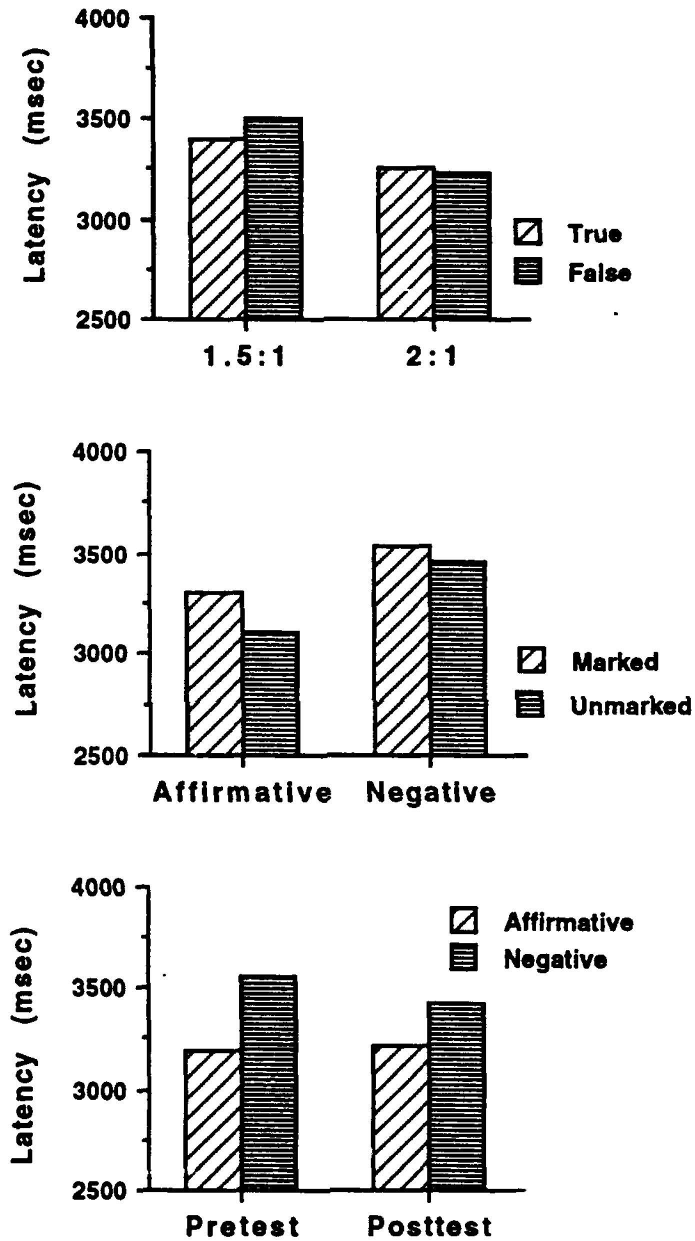

Figure 10. Coordination task latency cell means: True/false by velocity ratio (top panel), marked/unmarked by affirmative/negative (middle panel), and affirmative/negative by pre/posttest (bottom panel).

Component Task Training Sessions. Test statistics corresponding to statistically significant effects are presented in Table 8. As in the analysis of pre and posttest performance in the arrival time task, both accuracy and latency in the arrival time training task were significantly affected by ATD and the faster/closer variable during the training sessions. Accuracy increased over the three training days, whereas latency was not significantly affected by training. In addition, there were two significant interactions in the accuracy data, faster/closer with relative velocity and faster/closer with training day, and three significant interactions in the latency data, ATD with faster/closer, ATD with relative velocity, and faster/closer with relative velocity.

The cell means corresponding to the accuracy and latency interactions are presented in Figures 11 and 12, respectively. As shown in the top panel of Figure 11, although the overall configuration of the faster/closer trials and velocity ratio is similar to that in the arrival time task (see, Fig. 6), the faster/closer effect was no longer significant in the 1.5:1 velocity ratio trials, $F(1, 33) = 0.70$, *ns*, whereas the faster/closer effect had increased in the 2:1 velocity ratio trials, $F(1, 33) = 266.17$, $p < .001$. Thus, the interaction resulted from the combination of a large accuracy increase from the pretest trials in the 1.5:1 faster trials, a small decrease in the 1.5:1 closer trials, and roughly equal gains in the 2:1 faster and closer trials.

The faster/closer by day interaction shown in the bottom panel of Figure 11 reflected the significant increase over days in the faster condition, $F(2, 66) = 12.84$, $p < .001$, and a small but nonsignificant decrease in in the closer condition, $F(2, 66) = 1.51$, $p < .25$. This interaction is similar to Fischer et al.'s (in press) finding of increased accuracy in faster trials and decreased accuracy in closer trials following training. Together, these findings of an apparent accuracy tradeoff in the faster/closer trials support the hypothesis of resource-limited information processing in relative arrival time judgments.

Simple effects analyses of the latency interactions shown in Figure 12 indicated that the effect of ATD was significant in the closer condition, $F(1, 33) = 88.55$, $p < .001$, but not significant in the faster condition, $F(1, 33) = 5.19$, $p < .05$, and the effect of velocity ratio was significant in the in the closer condition, $F(1, 33) = 114.34$, $p < .001$, and nonsignificant in the faster condition, $F(1, 33) = .19$, $p < .67$. Both of these interactions suggest that subjects reached an internal decision deadline in the more difficult faster trials. In addition, the effect of velocity ratio was highly significant in the 1000 msec ATD condition, $F(1, 33) = 135.75$, $p < .001$, and attenuated in the 500 msec condition, $F(1, 33) = 40.05$, $p < .001$.

Finally, males ($M = 73.94\%$) performed at higher levels of accuracy than females ($M = 70.71\%$) across the three sessions. Although females ($M = 2579$ msec) responded faster than males ($M = 2686$ msec), this effect was not statistically significant.

Table 8

Significant Effects in the Component Training Task.

	Accuracy
Gender:	$F(1, 33) = 4.49, p < .05$
ATD:	$F(1, 33) = 869.62, p < .001$
Faster/Closer:	$F(1, 33) = 48.60, p < .001$
Day:	$F(2, 66) = 8.06, p < .001$
Faster/Closer X Velocity Ratio:	$F(1, 33) = 175.20, p < .001$
Faster/Closer X Day:	$F(2, 66) = 8.10, p < .001$
	Latency
ATD:	$F(1, 33) = 48.09, p < .001$
Faster/Closer:	$F(1, 33) = 73.19, p < .001$
Velocity Ratio:	$F(1, 33) = 104.70, p < .001$
ATD X Faster/Closer:	$F(1, 33) = 56.78, p < .001$
Faster/Closer X Velocity Ratio:	$F(1, 33) = 55.93, p < .001$
Velocity Ratio X ATD:	$F(1, 33) = 7.89, p < .01$

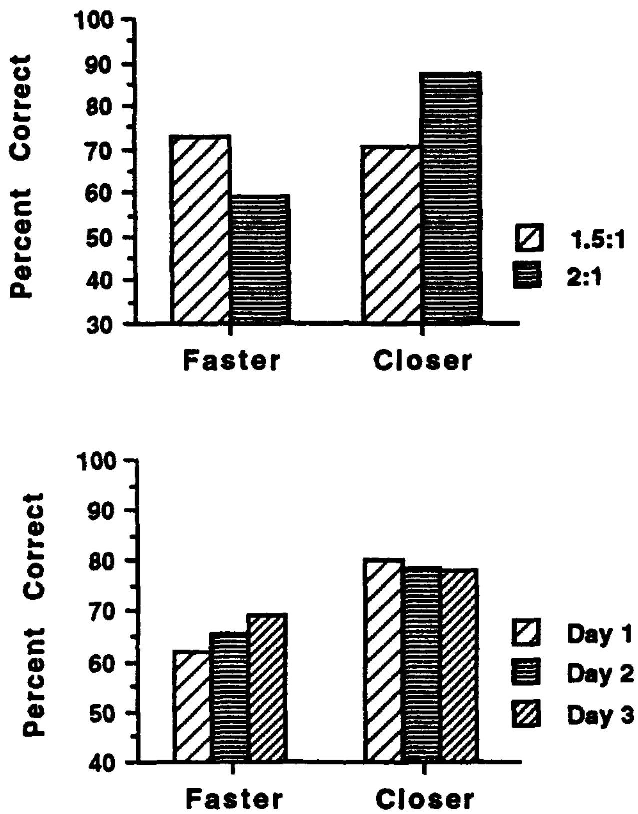

Figure 11. Component training task accuracy cell means: relative velocity by faster/closer (top panel) and day by faster/closer (bottom panel).

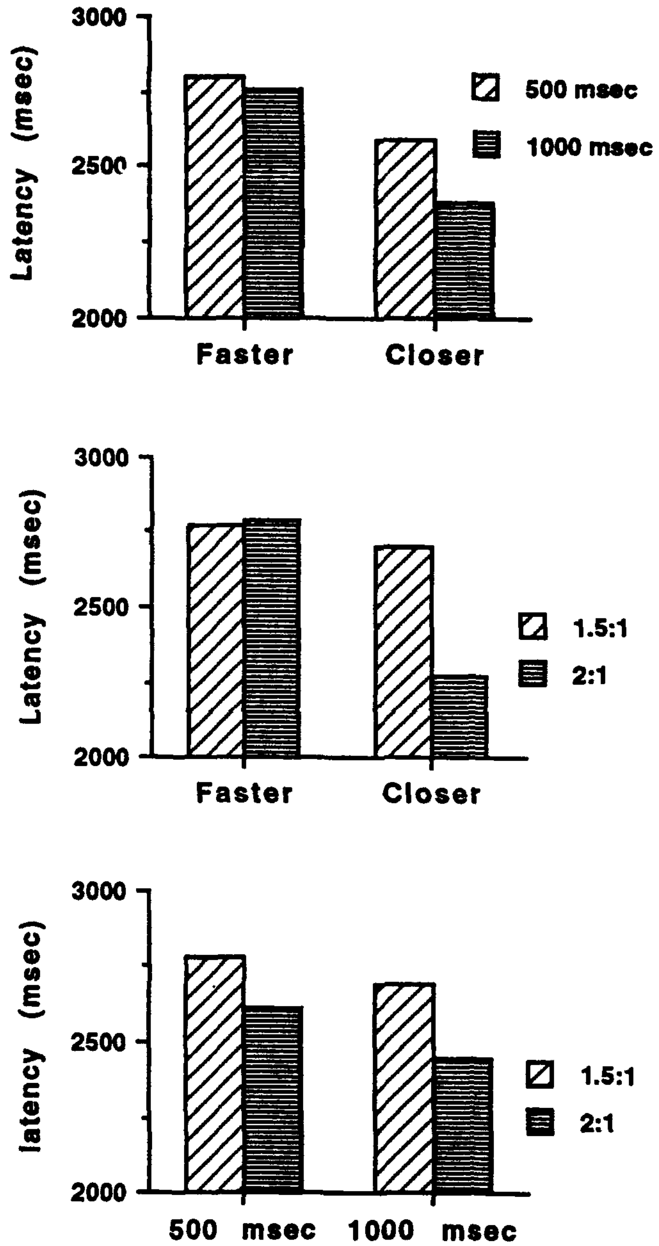

Figure 12. Component training task latency cell means: ATD by faster/closer (top panel), relative velocity by faster/closer (middle panel), and relative velocity by ATD (bottom panel).

Full Context Training Sessions. Test statistics corresponding to statistically significant effects are presented in Table 9. Accuracy in the arrival time-verbal coordination training task was significantly affected by ATD, velocity ratio, markedness, and training day. As expected, accuracy increased with ATD and across training sessions. Accuracy was also higher in sentences with unmarked adjectives. However, accuracy was not significantly affected by affirmation. Furthermore, accuracy was higher in the 2:1 velocity ratio, a finding taken at face value that is inconsistent with previous findings.

There were also significant interactions of velocity ratio with ATD and affirmation with true/false. The cell means corresponding to the velocity ATD and affirmation true/false interactions are presented in the top and center panels of Figure 13, respectively. A simple effects analysis indicated that the effect of velocity ratio was significant only in the 1000 msec ATD trials. This is consistent with our previous findings in the arrival time task (see, Fig. 6), however in this case performance was higher in the 2:1 velocity ratio trials. Regarding the affirmation with true/false interaction, a simple effects analysis indicated that affirmation significantly affected accuracy only in the false condition.

Although the faster/closer variable was not evaluated in the current ANOVA, a full evaluation of the relative velocity effect required an examination of performance in the faster/closer conditions. The bottom panel of Figure 13 presents the velocity ratio and faster-closer cell means across days. The relationship of the different trial types is ordinal with whether the winning object was leading or trailing when the display terminated and by how far the object was leading or trailing. Thus, higher accuracy in the 2:1 velocity ratio trials represented high levels of performance in the 2:1 closer trials only and was consistent with previous findings of a distance bias in relative arrival time judgments.

Regarding latency, subjects were significantly faster in the 1000 msec ATD, affirmative, 2:1 velocity ratio, and unmarked trials. There were also significant interactions of velocity ratio with day and velocity ratio, affirmation, and markedness with true/false. Regarding the velocity with day interaction, a simple effects analysis indicated that the effect of day was significant only in the 2:1 velocity ratio condition. In the interactions involving the true/false variable there was a significant difference between the true/false conditions only in the negative, marked, and 1.5:1 velocity ratio trials.

Table 9

Significant Effects in the Context Training Task.

	Accuracy
ATD:	$F(1, 31) = 338.84, p < .001$
Velocity Ratio:	$F(1, 31) = 17.63, p < .001$
Markedness:	$F(1, 31) = 14.68, p < .001$
Day:	$F(2, 62) = 7.00, p < .001$
Velocity Ratio X ATD:	$F(1, 31) = 11.34, p < .01$
Affirmation X True/False	$F(1, 31) = 13.55, p < .001$
	Latency
ATD:	$F(1, 31) = 31.8, p < .001$
Velocity Ratio:	$F(1, 31) = 97.38, p < .001$
Affirmation:	$F(1, 31) = 78.99, p < .001$
Markedness:	$F(1, 31) = 63.38, p < .001$
Velocity Ratio X Day:	$F(2, 62) = 9.98, p < .001$
Velocity Ratio X True/False:	$F(1, 31) = 19.41, p < .001$
Affirmation X True/False:	$F(1, 31) = 17.46, p < .001$
Markedness X True/False:	$F(1, 31) = 19.41, p < .001$

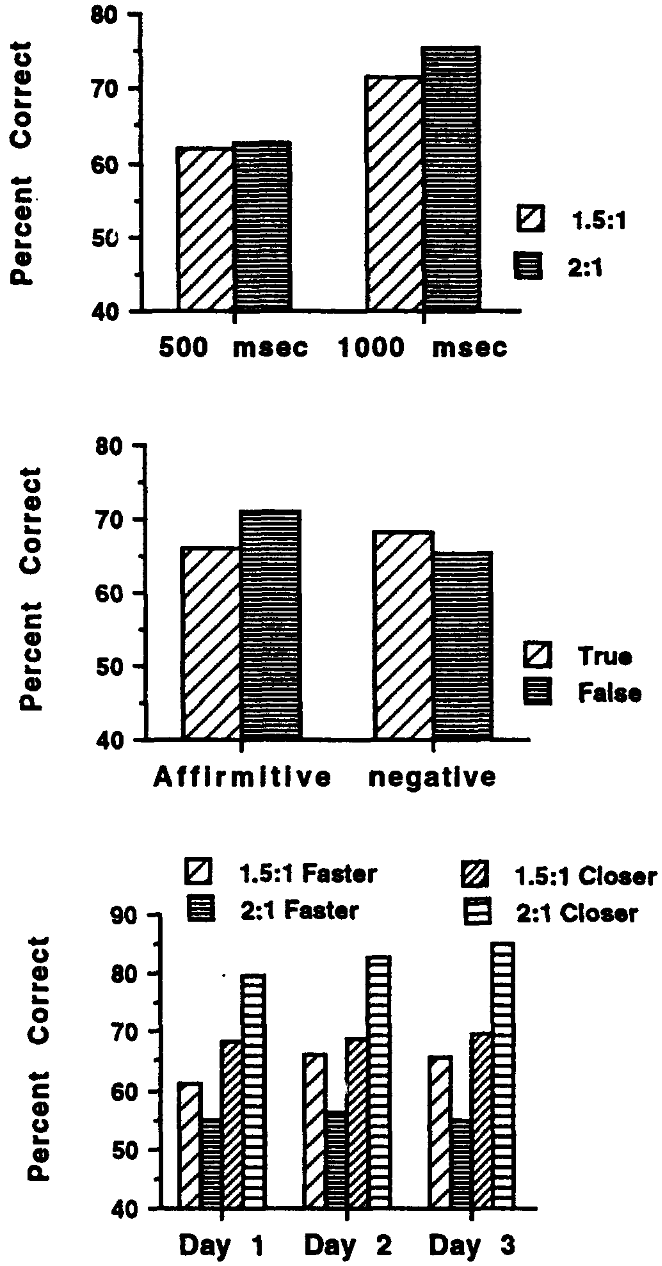

Figure 13. Contextual training task accuracy cell means: relative velocity by ATD (top panel), true/false by affirmative/negative (middle panel), and relative velocity by day (bottom panel).

Compression Effects. As noted earlier, compression effects are a marker of the coordination tasks described by Yee et al. (1991). Compression effects represent the combination of parallel and serial processing that occurs in these tasks and is most apparent in latency measures. Accordingly, we evaluated the latencies associated with the primary dynamic spatial and verbal effects of ATD and affirmation for evidence of compression. The present experiment also provided an opportunity to investigate the effe f practice and training on compression and whether compression was differenti affected by the componential and contextual treatments. Accordingly, the two groups' pretest data were evaluated together, whereas the posttest data were evaluated separately.

In the pretest sessions, the ATD component task effect of 85 ms was reduced to 29 ms in the coordination task, a relative reduction in effect size of 66%. Similarly, the component task effect of affirmation-negation was reduced from 497 ms to 366 ms in the coordination task, a relative reduction of over 25%. Compression in the posttest trials was comparable across training groups with both groups exhibiting compression in verbal processing and a lack of compression in dynamic spatial processing. In the componential group, the effect of affirmation was compressed from 445 ms in the verbal component to 240 ms in the coordination task, a relative reduction of 46%. In the contextual group the size of the affirmation effect in the verbal component 347 ms, was compressed to 174 ms, a reduction of 50%.

Although the lack of compression observed in the dynamic spatial information was not predicted, it was also not entirely unexpected. Given that both groups received feedback that focused on the arrival time component, albeit one in context of the coordination task, it was expected that the greatest changes would occur in the dynamic spatial variables with dynamic spatial processing becoming highly proceduralized. This was particularly true in the componential training group, where the effect of ATD in the arrival time task diminished to negative nine milliseconds - or approximately zero. Curiously, the effect size of ATD in the coordination task increased in both training groups following training. Thus, the lack of compression in the posttraining dynamic spatial data appears to be related to the differential effects of training in the component and coordination tasks.

Analyses of Individual Differences

In the present experiment we evaluated a number of individual differences hypotheses, using a variety of techniques. One set of hypotheses concerned the possibility that training accompanied by learning would cause changes in individual differences patterns within and across treatment groups. These differences, if any, would be apparent in the correlations among the pre and posttest scores. As noted above, feedback and practice caused increased levels of performance in the coordination task in both treatment groups and equivalent mean performance across groups. Thus, pre/post correlational differences within a group would illuminate the learning processes within that group. In contrast, across group differences would suggest that the treatments had fostered different strategies that capitalized on different ability profiles.

A second set of hypotheses concerned working memory and whether individual differences in working memory could account for the ability to coordinate information. Subsequently, the relationship of working memory capacity, type of training, and performance in the coordination, component, and training tasks was evaluated. Finally, we tested whether gender, working memory capacity, verbal processing ability, and sensitivity to relative velocity influenced whether one became a coordinator of dynamic spatial information as a result of training.

The individual differences analyses afforded several insights into the information processing changes that accompany training in a complex task. The pretest correlations among the information processing tasks were roughly equivalent across training groups. Following training the patterns of correlations in the two groups diverged. The divergence in correlations indicated that performance in the coordination task depended on different ability profiles in the pre and posttraining sessions and across groups. In particular, the contextual group's posttest performance showed a greater reliance on verbal processing. There was also an increase in working memory demands in the contextual group. In contrast, the componential group's dependence on working memory decreased during training and remained low during the posttests. Finally, the differential dependence on working memory was shown to be directly related to the different ability-performance profiles.

Pre/Post Correlations. Correlations of both treatment groups' pre and posttest performance in the arrival time, verbal, and coordination tasks are presented in Table 10. The arrival time pretest predicted the coordination task in both groups, but the verbal pretest did not correlate significantly with the coordination task in either group. The arrival time and verbal tasks were also not significantly correlated in either group. These correlations suggest that the major source of task difficulty and individual differences in the coordination pretest was the arrival time component. These correlations also show that prior to training the relationships among the various tasks were similar across treatment groups. In contrast, correlations among posttreatment measures were different across groups. Whereas the componential group's posttreatment correlations mirrored their pretreatment correlations, the contextual group's arrival time, verbal, and coordination posttest scores were heavily intercorrelated. Both component tasks predicted over 50% of the variance in coordination task performance and the component tasks were significantly correlated. In particular, the correlation of the contextual group's performance in the verbal and coordination tasks was significantly greater than the corresponding correlation in the componential group, $z = 2.74$, $p < .01$. These correlations indicate that the information processing in these tasks was more interdependent in the contextual group's posttests than in the pretest condition or in the componential group's performance overall. Thus, it appears that the influence of individual differences in verbal processing was substantially increased in the contextual group's posttest performance.

To evaluate this finding further, we conducted a backward stepwise regression within each group, entering both pre and posttests as predictors of coordination posttest scores. In this procedure each of the tasks was evaluated as a predictor in the context of the other tasks and only those predictors that were significant in context were retained in the regression. Both regressions were statistically significant, $F(3, 29) = 38.02$, $p < .001$, $R^2 = .80$, and $F(2, 32) = 9.23$, $p < .001$, $R^2 = .37$, in the contextual and componential groups, respectively. Thus, the component tasks explained a greater proportion of variance in the contextual group. Furthermore, the contextual group's verbal pre and posttests and arrival time posttest were all significant predictors, $\beta = .292$, $t(29) = 2.38$, $p < .05$, $\beta = .308$, $t(29) = 2.44$, $p < .05$, and $\beta = .501$, $t(29) = 5.45$, $p < .001$, respectively. Whereas in the componential group only the verbal pretest and arrival time posttest were significant predictors, $\beta = .367$, $t(32) = 2.49$, $p < .05$, and $\beta = .385$, $t(32) = 2.62$, $p < .05$, respectively. That the contextual group's pre and posttraining verbal tasks were both significant predictors suggests that posttraining verbal processing influenced the coordination task differently than pretraining verbal processing. A plausible explanation for this finding is that the significant relationship of the verbal pretest and coordination posttest represents an indirect effect of verbal ability (i.e. pretest verbal ability affected the effectiveness of training), whereas the relationship among the posttests represents the direct effect of verbal mediation during posttest performance. In contrast, individual differences in componential group's verbal processing may have affected posttest performance in the coordination task via the training sessions only.

Table 10

Pre and Posttraining Intertask Correlations.

	Contextual Group					
	Pre: AT	VB	CD	Post: AT	VB	CD
AT	(.77)			(.69)		
VB	-.02	(.84)		.42*	(.75)	
CD	.47*	.27	(.82)	.74**	.73**	(.94)
	Componential Group					
	Pre: AT	VB	CD	Post: AT	VB	CD
AT	(.72)			(.75)		
VB	.25	(.88)		.03	(.84)	
CD	.46*	.33	(.82)	.49**	.23	(.88)

Note. AT = arrival time task, VB = verbal task, CD = coordination task. Reliabilities presented in parentheses on the diagonal are Spearman Brown corrected odd/even split half correlations. $N = 33$ and $N = 35$ in the contextual and componential treatment groups, respectively.
*$p < .01$, **$p < .001$, two-tailed.

Working Memory. To evaluate working memory's potential to account for coordination ability we first computed working memory factor scores for each participant (see the appendix for details). Subsequently, these estimates of working memory capacity were entered as the third predictor in a hierarchical multiple regression of coordination task performance on component task performance. The analysis was performed across treatment groups and employed only pretest measures. A corresponding simultaneous regression analysis was also performed. The hierarchical regression of the coordination task on the arrival time and verbal tasks was significant, $R^2 = .29$, $F(2, 65) = 12.93$, $p < .001$, and both the arrival time and verbal task's performance were significant predictors of the coordination task, $\beta = .440$, $t\ (65) = 4.15$, $p < .001$, and $\beta = .247$, $t\ (65) = 2.34$, $p < .05$, respectively. Finally, working memory significantly added to the overall prediction with, $\Delta R^2 = .08$, $F(3, 64) = 8.07$, $p < .01$. Thus, the hierarchical analysis supported both the coordination model and the use of working memory to account for some aspects of coordination. However, the simultaneous regression analysis indicated that the verbal task was not a significant predictor controlling for both the arrival time task and working memory, $t(64) = 0.992$. The regression coefficients corresponding to the arrival time task and working memory in the simultaneous analysis were, $\beta = .367$, $t(64) = 3.54$, $p < .001$, and $\beta = .327$, $t(64) = 2.84$, $p < .01$, respectively. Together, these results suggest that working memory was responsible for both mediating performance in the verbal component task and the coordination of dynamic spatial and verbal information in the coordination task. These results also provide further evidence that of the two component tasks, arrival time judgments were the major source of individual differences and task difficulty in the arrival time-verbal coordination pretest.

Table 11 presents the correlations of the working memory factor score with mean performance in the verbal, arrival time, and coordination tasks. The correlations were computed across treatment groups for the pretest performance measures and separately for the training trials and posttests. Prior to training, each of the tasks were significantly but moderately correlated with working memory. However, following the initiation of training the pattern of correlation in the two groups diverged dramatically; the between group differences became statistically significant and remained so over the three training days (p's $< .01$).[2] Consequent with the initiation of training the proportion of variance associated with working memory capacity increased for the contextual group and decreased for the componential group. On the first day of training individual differences in working memory capacity accounted for approximately 58% of the variance in the contextual group's performance, whereas in the componential group working memory capacity was associated with only 4% of the variance. The correlation in the contextual group decreased over three days of training, but remained statistically significant accounting for 34% of the variance on the final day of training. The decrease in variance associated with working memory capacity suggests that learning was taking place, whereas the remaining dependence on working memory capacity suggests that the task was not fully proceduralized (Anderson, 1983) or automatized (Schneider et al., 1984). In contrast, performance in the component group was independent of working memory capacity from the first to last day of training. This suggests that performance in the arrival time task was largely proceduralized within the initial training session. This is consistent with the previous finding that performance in the arrival time task becomes asymptotic within a single training session (Fischer et al., in-press).

Figure 14 is a graphic representation of the within group relationship of the coordination task posttest and working memory capacity. Both the correlation and the slope of the function relating working memory and the coordination task posttest were significantly greater in the contextual group than in the componential group, $z = 2.35$, $p < .05$, and , $z = 2.59$, $p < .01$, respectively. Thus, the increased performance in the contextual group came with the cost of increased dependence on working memory, whereas the increased performance in the componential group may have been accompanied by a small decrease in working memory demands. Apparently, it is possible to use different training procedures, obtaining identical performance levels in a complex task, and have highly disproportionate reliance on working memory resources. In this case the group with the more efficient use of processing capacity was trained on the component alone, whereas the less efficient group was trained on the component within the context of the larger task.

Finally, to more fully evaluate the relationship of working memory capacity and the different ability profiles realized in the treatment groups, we compared the proportions of shared variance among the posttests and the same variance controlling for working memory. Table 12 contains squared correlations representing the shared variance among the arrival time, verbal, and coordination posttests and the corresponding squared semipartial correlations controlling for individual differences in working memory. As can be seen in Table 12, the overall proportion of shared variance among the posttests was greater in the contextual group than in the componential group. However when working memory was controlled for, the shared variance among the tasks was roughly equivalent across groups. Thus, the differential demands on working memory capacity were directly related to the different ability profiles.

Table 11

Correlations of Working Memory with Component, and Coordination Tasks.

Pretraining:[1]	Combined			
Verbal	.45**	(.86)		
Arrival Time	.28*	(.74)		
Coordination	.48**	(.82)		
Training Trials:[2]	Contextual Group		Component Group	
Day 1	.76**	(.93)	.20	(.83)
Day 2	.66**	(.91)	.02	(.83)
Day 3	.62**	(.89)	.07	(.92)
Posttraining:[2]				
Verbal	.60**	(.75)	.29	(.84)
Arrival Time	.58**	(.69)	.19	(.75)
Coordination	.73**	(.94)	.32	(.88)

Note. Reliabilities presented in parentheses on the diagonal are Spearman Brown corrected odd/even split half correlations. [1]$N = 68$. [2]$N = 33$ and $N = 35$ in the contextual and component treatment groups, respectively.
*$p < .05$. **$p < .001$, two-tailed.

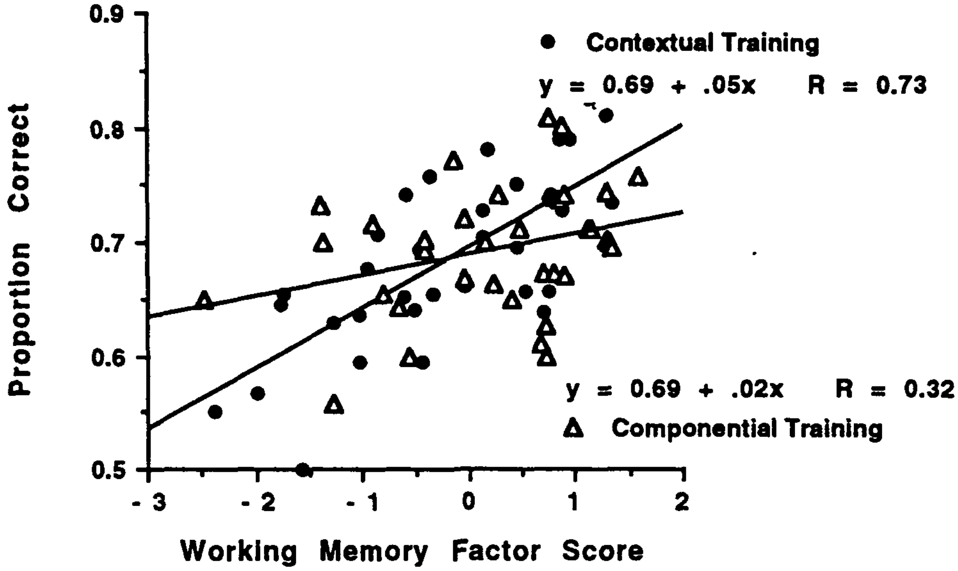

Figure 14. Within-group regressions of coordination task posttest performance on working memory factor scores.

Table 12

Posttraining Tasks: Squared Intertask Correlations and Squared Semipartial Correlations Controlling for Working Memory.

	Contextual Group			
	Squared Correlations		Squared Semipartials	
	AT	VB	AT	VB
VB	.18		.01	
CD	.53	.55	.15	.14
	Component Group			
	Squared Correlations		Squared Semipartials	
	AT	VB	AT	VB
VB	.00		.00	
CD	.24	.05	.20	.02

Dynamic Spatial Coordination. As noted above, one indication of an individual's ability to coordinate dynamic spatial information is the extent to which they integrate relative velocity and distance information in relative arrival time judgments (Law et al. in press). Furthermore, training on the arrival time task has been shown to increase the integration of dynamic spatial information (Fischer et al., in press). Overall, it appears that the coordination of dynamic spatial information represents a complex mix of experientially derived strategies and information processing resources. In these analyses, we first examined whether training increased subjects' integration of relative velocity and distance information in the arrival time and arrival time-verbal coordination tasks. Second, we evaluated if being an integrator was related to one's gender, working memory capacity, sensitivity to relative velocity, and verbal processing ability. To categorize subjects as integrators or biased, the following decision rule was employed: an integrator was above chance on both the faster and closer trials (i.e., representing both relative velocity and distance information), whereas a biased judge was below the criterion of integration in one of the trial types. Chance performance was determined by constructing a 95% confidence interval around the 50% accuracy level of each trial type. A preliminary examination of the data failed to find meaningful differences between treatment groups. Accordingly, the analyses were conducted across treatment groups.

The breakdowns of the pre and posttest classifications for both the arrival time and coordination tasks are presented in Table 13. The top panel of Figure 15 depicts subjects' performance in the arrival time pretest. In the arrival time pretest only five subjects were classified as integrators, whereas 63 exhibited biased judgments. Furthermore, the majority of biased subjects showed a distance bias, (i.e., the lower right quadrant of the graph), whereas a limited number were overly reliant on velocity information (i.e., the upper left quadrant of the graph). The bottom panel of Figure 15 presents subjects' performance in the arrival time posttest. Apparently, a large number a subjects had become integrators in the posttest trails. A McNemar's change test corrected for discontinuity was used to assess the difference in pre/post classifications and the obtained Chi-square was significant, $\chi^2(1) = 18.89$, $p < .001$. Thus, in the arrival time task there was a significant change from pretest to posttest in the number of subjects that integrated relative velocity and distance information.

Posttest classifications of performance in the arrival time task indicated that 29 individuals had become integrators, whereas 39 individuals remained biased. Using these classifications, univariate tests revealed that integrator and biased subjects were significantly different in terms of sensitivity to relative velocity, $F(1, 66) = 8.23$, $p < .01$, verbal processing bility, $F(1, 66) = 8.97$, $p < .01$, and working memory capacity, $F(1, 66) = 9.94$, $p < .01$. Table 14 contains means and standard deviations by classification. A discriminant analysis was performed using these variables to identify integrators and biased individuals. The discriminant function was significant, *Wilk's* $\Lambda = .808$, $F(4, 63) = 3.75$, $p < .01$, with nearly 20% of the total variance in group membership attributable to the function. The correlations of the variables with the discriminant function and standardized coefficients are also presented in Table 14. Sensitivity to relative velocity, verbal processing ability, and working memory capacity were all significantly correlated with the discriminant function, with roughly the same degree of association. Gender was not correlated with the function. Examining the standardized coefficients, it is apparent that, controlling for the other variables, sensitivity to relative velocity had the greatest impact on group membership, followed by working memory capacity, and verbal processing ability. In this analysis, gender did not influence whether subjects became coordinators.

Table 13

Pretest and Posttest Classifications (Integrator vs. Biased) for the Arrival Time Component and the Arrival Time-Verbal Coordination Tasks.

		Component Task	
		Posttest	
		Biased	Integrator
Pretest	Biased	37	26
	Integrator	2	3
		Coordination Task	
		Posttest	
		Biased	Integrator
Pretest	Biased	27	28
	Integrator	3	10

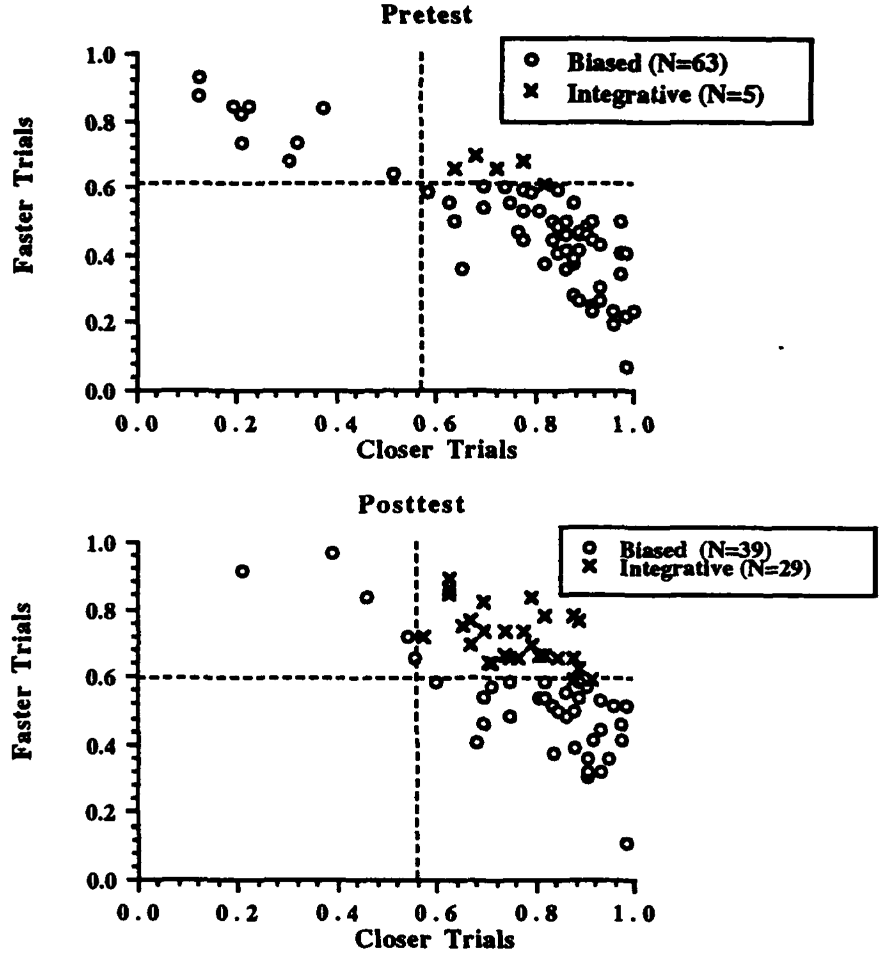

Figure 15. Integrative or biased subjects in the arrival time component pretest (top panel) and posttest (bottom panel).

Table 14

Arrival Time Component Task Integrator/Biased Group Descriptives and Discriminant Analysis.

	Integrator (*N*=29)		Biased (*N*=39)	
	M	(*SD*)	*M*	(*SD*)
Relative Velocity	90.64	(3.38)	86.94	(6.43)
Verbal	93.50	(4.91)	88.86	(7.22)
Working Memory	.42	(.88)	-.31	(.98)

	Standardized Coefficients	Correlations
Gender	.017	.131
Relative Velocity	.511	.724
Verbal	.379	.756
Working Memory	.430	.795

	Discriminant Analysis Predictions: Integrator	Discriminant Analysis Predictions: Biased
Performance Based Classifications		
Integrator	23	6
Biased	17	22

The bottom panel of Table 14 presents the breakdown of performance based classifications and discriminant function predictions for the arrival time task. Overall 66% of the classifications were in agreement, with 79% of the integrators and 56% of the biased subjects correctly classified by the discriminant function. These results suggest that our classification rule may have been overly conservative in determining which subjects were integrators. More likely, the predictor variables of working memory capacity, sensitivity to relative velocity, and verbal processing ability are *necessary but not sufficient* to account for whether an individual becomes an integrator in the arrival time task. That there are other important predictors is consistent with the finding that only 20% of the variance in group membership was explained by the function. Among variables that were not assessed, motivation and previous dynamic spatial experience could play an influential role.

As in the arrival time task, a significant number of subjects became integrators in the coordination task following training, $\chi^2(1) = 18.58, p < .001$. In the posttest coordination task 38 subjects were classified as integrators and 30 subjects were classified as biased. Univariate tests revealed significant differences between classifications in verbal processing ability, $F(1, 66) = 27.03, p < .001$, and working memory capacity, $F(1, 66) = 19.34, p < .001$, with a marginal difference in sensitivity to relative velocity, $F(1, 66) = 3.91, p < .06$. The associated means, standardized coefficients, and correlations with the discriminant function are presented in Table 15. The discriminant function was significant, *Wilk's* $\Lambda = .643$, $F(4, 63) = 8.74, p < .001$, accounting for almost 36% of the total variance in the group membership. All four predictor variables were significantly correlated with the discriminant function, with both verbal ability and working memory capacity demonstrating a high level of association. Examining the standardized coefficients, it is apparent that verbal processing ability was most influential in determining who was an integrator followed by nearly equal contributions of working memory capacity and gender. Controlling for the other predictors, sensitivity to relative velocity was not influential in determining who was an integrator in the coordination task. Comparing the predictions of the discriminant analysis with the performance based classifications, 78% of the cases were in agreement, with 92% of the integrators and 60% of the biased subjects classified correctly. Although 92% agreement in the case of subjects classified as integrators is excellent, the 40% of subjects classified as biased and predicted to be integrators suggests that once again the predictor variables were necessary but not sufficient to determine who was an integrator. Figure 16 depicts coordination task performance during the pretest (top panel) and posttest (bottom panel).

Regarding gender, classifications based on performance in the coordination task indicated that 24 males and 11 females were integrators and the discriminant analysis predicted 29 males and 15 females to be integrators. In both cases nearly a 2:1 ratio of males to females were described as integrators. This contrasts with the arrival time task, where nearly equal groups of 16 males and 13 females were classified as integrators and 19 males and 20 females biased, with the discriminant function predicting 24 males and 16 females as integrators. Interestingly, there were mean differences in both tasks that were associated with gender and the difference was larger in the arrival time task. Although one finding involves individual differences and the other mean differences, one would expect that the group exhibiting higher performance overall would also have a higher proportion of integrators. The source of this discrepancy is not apparent in the data, but may relate to our categorization procedure. Possibly a procedure using a higher criterion would give different results.

Table 15

Arrival Time-Verbal Coordination Task Integrator/Biased Group Descriptives and Discriminant Analysis.

	Integrator (N=38)		Biased (N=30)	
	M	(*SD*)	*M*	(*SD*)
Relative Velocity	89.66	(3.89)	86.99	(7.05)
Verbal	94.01	(4.11)	86.81	(7.18)
Working Memory	.42	(.80)	-.53	(.98)

	Standardized Coefficients	Correlations
Gender	.386	.366
Relative Velocity	.039	.327
Verbal	.651	.859
Working Memory	.394	.727

		Discriminant Analysis Prediction	
		Integrative	Biased
Performance Based Classifications			
	Integrative	35	3
	Biased	12	18

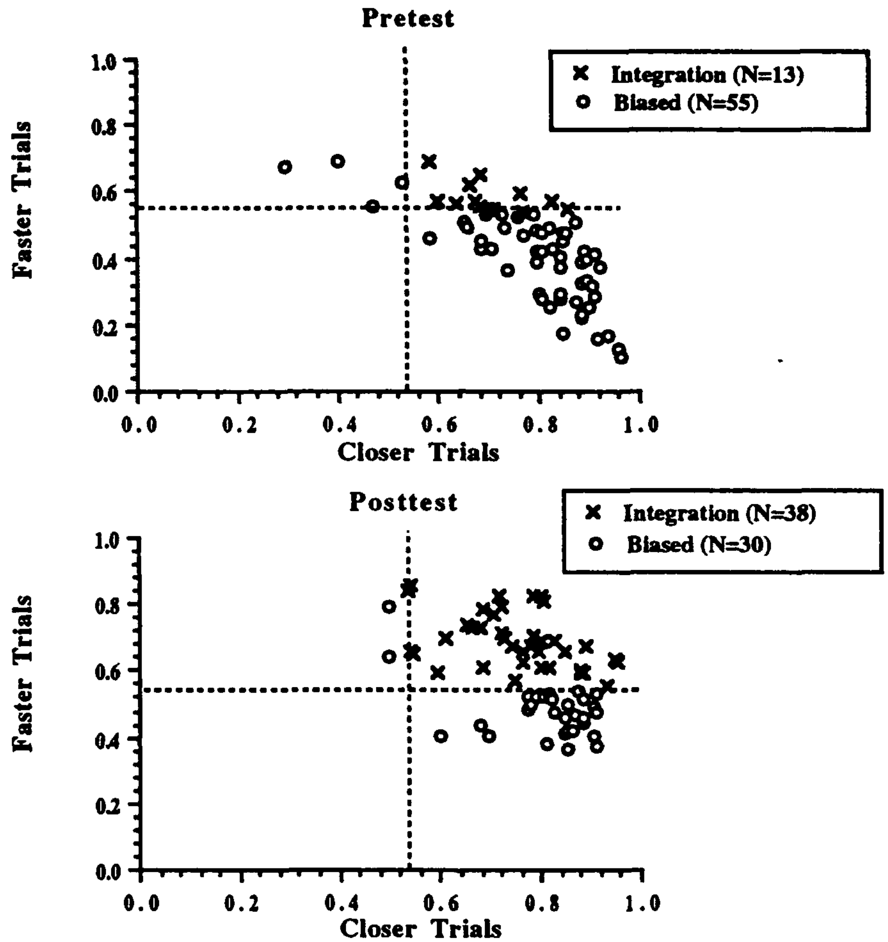

Figure 16. Integrative or biased subjects in the coordination pretest (top panel) and posttest (bottom panel).

Summary and Conclusions

In general the ANOVA results supported the validity of the variable manipulations within each of the experimental tasks. The ATD and faster/closer variables were major determinants of performance in the arrival time task and the affirmation/negation variable affected performance in the verbal task. Together, the effects of ATD and affirmation affected performance in the coordination task. Further, there were significant accuracy gains in all three tasks following training. However, latency improved only in the verbal task. This suggests that the single route to improved performance in the verbal task was greater efficiency in verbal processing, whereas improvement in the dynamic spatial component may have involved a mixture of increased processing efficiency and increased attention allotted to relative velocity and distance as multiple sources of information. The most interesting finding in the mean differences analyses was the lack of a difference between the two training groups. This conflicts with the previous finding of Fabiani et al. (1989) that training on separate components leads to higher performance levels. Thus, the advantage of componential training over contextual training appears to be task specific. Just as likely, the advantage or lack of it - reflects the interaction of a particular task and instruction set. Whichever, generalized statements regarding the relative efficiency of componential and contextual training appear unwarranted. Finally, the compression effect described by Yee et al. (1991) was observed in both the dynamic spatial and verbal pretraining data. However in the posttraining data, compression was observed only in the affirmation variable. The reason for the lack of compression in the posttraining ATD variable is not entirely clear. However, it appears to be related to differential training effects in the component and coordination tasks.

The individual differences analyses, which were the primary focus of the present study, afforded several insights into the information processing changes that accompany training in a coordination task. The pretraining correlations among the information processing tasks were roughly equivalent across training groups. Following training the patterns of correlations in the two groups diverged. The divergence in correlations indicated that performance in the coordination task depended on different ability profiles in the pre and posttraining sessions and across groups. In particular, posttraining performance in the contextual group showed greater reliance on verbal processing. There was also an increase in working memory demands in the contextual group. In contrast, the componential group's dependence on working memory decreased during training and remained low during the posttests. Finally, the differential dependence on working memory was shown to be directly related to the different ability-performance profiles. Thus, the the componential group's posttraining performance conforms to the pattern expected of a group trained with low complexity consistent information, whereas the contextual groups performance is closer to that expected of a group trained with complex inconsistent information (Ackerman, 1988).

Nevertheless, the question remains - what was the nature of the processing underlying these differences? It was definitely not the case that one group engaged in verbal processing and the other did not. Successful performance in the coordination task requires reading the sentence, observing and judging the dynamic event, and verifying the sentence. Thus, the differences in individual differences profiles did not result from processing different information, but from processing information differently. One plausible explanation is that the componential group processed the dynamic spatial information more efficiently, leaving reserve capacity so that performance in the coordination task was not impacted by individual differences in verbal processing. Clearly, the verbal task was not a great source of difficulty for either group with posttraining means of 93.70% and 94.06% in the contextual and componential groups and mean latencies more than a second less than the arrival time and coordination tasks. Thus, verbal processing only became a major source of difficulty and individual differences under the load of concurrent processing with the arrival time task. Having received extended practice and feedback in the context of the coordination task, the contextual group may have become more efficient at "managing" the different sources of information. However, they managed the information with an added cost to their overall processing capacity. In particular, managing information would increase the load on executive component of working memory (see e.g., Baddeley, 1986). In contrast, the component treatment group became efficient and accurate in their arrival time judgments and in doing so increased their coordination task performance with a slight decrease in overall processing demand.

Apparently, these differences were related to differences in the functional consistency (Carlson & Lundy, 1992; Fisk et al., 1988) of mappings among the feedback, stimuli, and responses in the two conditions. In both groups the feedback was consistently mapped onto the arrival time task. However, this mapping was functionally consistent only in the componential group: when they were "Right," their arrival time judgment was correct and when they were "Wrong," their arrival time judgment was incorrect. Similarly, the actual judgment was consistent across trials in the componential group; which object will arrive first? Thus, the task relevant components were clearly and consistently specified. As a result, their arrival time judgments were automatized to the extent that is possible in such a complex task. That their arrival time judgments became "automatized" allowed them to increase their performance in the coordination task without a concurrent increase in processing demands. In contrast, the feedback in the contextual condition was not functionally consistent. When subjects in the contextual group were "Right," they were correct in both the sentence verification and the arrival time judgment (assuming they were not incorrect in both). However, when they were "Wrong" they may have performed either the sentence verification or the arrival time judgment incorrectly. To the degree that the contextual group's feedback was less consistently mapped to the task, they were less likely to automatize their performance in the dynamic spatial component. Furthermore, the addition of verbal information increased the complexity in the coordination task and may have effectively altered the consistency of the judgment type across trials. For example, depending on the sentence the judgment could have been perceived as which object will arrive first on one trial and which object will *not* arrive first on another trial. Overall, the added complexity and decreased consistency would have interfered with the automatization of their performance. Finally, the combined effects of inconsistent mapping, increased complexity, and the resultant lack of automatization caused the contextual group to adopt an active information management strategy. This would have been adopted early in training during what Ackerman (1988) calls the cognitive phase of skill acquisition and maintained throughout the course of training. Thus, although the different feedback treatments led to quantitatively identical performance in terms of accuracy and latency, performance in the two groups was qualitatively different, as evidenced by the individual differences data. Accordingly, we can predict that given additional processing demands performance in the contextual group would deteriorate more quickly than in the componential group.

An additional finding regarding working memory capacity was that it accounted for some aspects of information coordination ability. Although this may seem common sense, given the definitions of the two constructs, it becomes particularly interesting in light of the findings of Morrin et al. (1993) and Kyllonen and Christal (1990). Morrin et al. (1993) evaluated the possibility that general reasoning ability could account for information coordination and failed to find a relationship. In contrast, Kyllonen and Christal (1990) evaluated the relationship of working memory and general reasoning ability and obtained estimates of shared variance ranging from 55% to 86%. In the present experiment we found that working memory capacity accounted for 8% of coordination task variance that was not accounted for by performance in the component tasks. Generally, systematic coordination task variance beyond that accounted for by the component tasks has been considered to represent coordination ability. In this case, internal consistency estimates indicated that there was considerably more than 8% of the overall variance that was systematic and not accounted for by the component tasks. Accordingly, it appears that working memory accounts for only certain aspects of coordination ability. Secondly, combining the present results with those of Morrin et al. (1993) and Kyllonen and Christal's (1990), it seems that these aspects are likely to be independent of general reasoning ability. However, Morrin et al. (1993) also found that general reasoning ability related to the verbal component factor which in turn was related to the arrival time-verbal coordination task. Thus, given the partitioning of working memory variance into that which is common to the component and coordination tasks and that which relates to the coordination task independently, it is likely that the common variance corresponds to the variance that Kyllonen and Christal (1990) found to be related to general reasoning. Furthermore, it is this variance that increased in the contextual training group's posttest performance.

Finally, we found that training increased the proportion of subjects that integrated relative velocity and distance information in their relative arrival time judgments. This effect was realized across treatment groups and was present in both the arrival time and coordination tasks. Consistent with the findings of Fischer et al. (in press), sensitivity to relative velocity was most influential in whether one became an integrator of dynamic spatial information in the arrival time task. Sensitivity to relative velocity was followed by working memory capacity and verbal processing ability. Given the dynamic spatial nature of arrival time task, it is likely that the variance in verbal processing ability associated with being an integrator represents the general reasoning ability discussed above. Given previous research regarding dynamic spatial reasoning (Law et al., 1993; Law et al., in press), it is surprising that gender did not influence whether one became an integrator in the arrival time task. However, it may be that the dichotomcus variable of integrator/biased determined by the current criteria represents a different dimension than the full continuum of individual differences in dynamic spatial performance. In the coordination task the most influential variable in becoming an integrator was verbal processing ability followed by working memory capacity and gender.

In conclusion, this study evaluated the relative effectiveness of componential and contextual training in the arrival time-verbal coordination task. Although the mean differences analyses indicated that the two treatments were equivalent, the individual differences analyses painted an entirely different picture. If one's goal was goal was to produce resource-free processing, the componential treatment was to be preferred. As we believe this result was the product of the functional consistency of the training procedures, this is not a simple endorsement of componential over contextual training. Nevertheless, a program of training components to the criterion of "automatic" processing should be given further consideration as a way to reduce cognitive load in complex tasks. In the end, given the differences in the two types of analyses conducted and the different conclusion that would have been reached upon the basis of mean differences alone, this paper echoes Cronbach's (1957) call for the combination of the the two schools of scientific psychology and an increased merger of the experimental and individual differences methodologies.

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Footnotes

[1] This finding applies to relative arrival time judgments in the transverse viewing plain such as the judgments in the current tasks and those performed by radar operators and air traffic controllers. It is likely that a large proportion of arrival time information involving approaching objects is perceived directly (see e.g., Gibson, 1986; Schiff & Oldak, 1990; Todd, 1981; Tresilian, 1991), however, this also may vary with the salience of information and the need to make temporal and motor adjustments (see e.g., DeLucia, 1991; Kaiser & Mowafy, in press; Wann, Edgar, & Blair, in press).

[2] It is important to remember that the training tasks were not the same across groups and that the crucial comparisons regarding the effectiveness of training procedures and working memory capacity concern the coordination task posttest. However, the difference between groups on the training days shows that the contextual treatment placed a greater burden on working memory than the componential treatment.

Appendix

Means, standard deviations, and Spearman-Brown odd-even reliability coefficients for the working memory tasks are presented in Table A1. The verbal verification span true\false scores were not reliable and the spatial verification span true\false and recall scores evidenced less than desirable reliability characteristics. The low reliability in these measures was due largely to ceiling effects that restricted individual differences. Given the reliability estimates, it was decided that only the five most reliable measures would be used in an initial factor analysis and that a second analysis would be conducted using only the three most reliable measures.

Table A1

Working Memory: Means, Standard Deviations, and Reliabilities.

Condition	Mean (*SD*)	Reliability
Verbal:		
Four Term Ordering Recognition	79.66 (15.64)	.83
Verification Span Recall	85.74 (11.41)	.83
Verification Span True\False	96.87 (3.97)	.04
Spatial:		
Four Term Ordering Recognition	62.99 (21.36)	.83
Verification Span Recall	91.66 (7.72)	.47
Verification Span True\False	94.79 (5.55)	.44

In both analyses, a principal components extraction was combined with a regression analysis to determine exact factor scores for each subject. In both analyses the principal components extraction yielded a single component with an eigenvalue greater than one. Accordingly, each subject received a single factor score in both analyses. In the five variable analysis the component accounted for 51.7% of the individual differences variance, whereas in the three variable analysis the component accounted for 63.7% of the variance. The communalities and factor score coefficients for both analyses are presented in Table A2. In both analyses the verbal four-term ordering task recognition scores had the highest communality and thus the greatest factor score coefficients, whereas the other scores had roughly equivalent loadings and coefficients. Looking at both Tables A1 and A2 and comparing reliabilities with communalities, it can be seen that the five variable solution explained all of the reliable variance in the spatial verification span measures. Thus the stable variance in these two measures appeared to be "pure" indicators of the working memory construct represented by the component. Nevertheless, it was decided that only the working memory factor scores from the three variable analysis would be used in the analyses that follow. This was based on the finding that the three variable analysis explained a greater proportion of the variance in the three variables with the greatest individual differences; it may be that the restriction of range in the spatial verification span measures prevented the assessment of some aspect of working memory that was common to the variables employed in the three variable analysis. Furthermore, the factor scores from the two analyses correlated, $r(66) = .92$, $p < .001$, thus indicating that the two sets of scores were largely redundant. Although the primary purpose of these analyses was to obtain a composite estimate of working memory capacity, the factor structures in both analyses support the conclusion that the common variance in these tasks represents a single working memory factor that underlies performance in both spatial and verbal tasks.

Table A2

Communalities and Factor Score Coefficients.

Condition	Communality	Coefficient
Five Variable Solution:		
Verbal:		
Four Term Ordering Recognition	.677	.318
Verification Span Recall	.496	.273
Spatial:		
Four Term Ordering Recognition	.448	.259
Verification Span Recall	.498	.273
Verification Span True\False	.464	.263
Three Variable Solution:		
Verbal:		
Four Term Ordering Recognition	.791	.466
Verification Span Recall	.566	.394
Spatial:		
Four Term Ordering Recognition	.552	.389

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