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Applying multimedia learning theory to map learning and driving navigation

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ABSTRACT

The effects of multimedia instructional materials on map learning and subsequent navigation were examined. Participants studied visual and/or verbal driving directions presented simultaneously, sequentially, or exclusively. Memory recall for the studied information was tested, and participants then attempted to navigate the studied routes as well as a novel route in a driving simulator. Dual modality materials with oral narrative directions and a visual map produced significantly superior performance for recall, navigational accuracy, and number of destinations reached than presentation in either modality alone. The presence of a map facilitated route recall but not subsequent ability to navigate routes in the simulator. Map-first dual modality sequential presentation enhanced wayfinding efficiency on the novel route compared to narration-first sequential presentation. Simultaneous presentation of dual modality materials allowed more destinations to be reached compared with sequential presentation. The results demonstrate that multimedia instructional materials can facilitate map learning and driving navigation, extending the applications of multimedia learning theory to this novel domain.

1. Introduction

As evidenced by the popularity of websites such as MapQuest, which claims over 40 million unique visitors each month (MapQuest Internet – Overview, 2007), many drivers rely on traditional navigation aids such as printed maps and step-by-step directions to assist in wayfinding. The research presented here assessed whether dual modality (i.e., visual and verbal) presentations of navigation information produced an advantage over single modality presentations. Additionally, the impact of timing (sequential presentation vs. simultaneous presentation) of dual modality materials with maps and driving directions was examined. Broadly speaking, the goals of this research were to extend the tenets of multimedia learning theory to a novel applied context as well as to find ways to improve map learning and navigation.

1.1. Route learning and navigation

Navigation research typically focuses on two separate but related aspects of route learning: map acquisition and direction retention. Both maps and verbal directions are commonly believed to lead to the formation of a conceptual representation, or cognitive map (Tolman, 1948), of a route that is used to navigate through the environment (Taylor, 2005). Thus, one of the objectives in route learning and navigation research is to understand how cognitive maps are acquired and what kind of

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information is represented, or made explicit, in them (see, for example, Stankiewicz & Kalia, 2007; Thorndyke & Hayes-Roth, 1982; Tversky, 1981).

1.1.1. Map learning

An important aspect of route learning is how knowledge of maps is acquired. Lynch (1960) pointed out that most maps contain several basic components, including paths, edges, districts, nodes, and landmarks, that can be incorporated into a cognitive map and facilitate recall of information within the map. Mental map acquisition progresses such that maps tend to be learned in a global to local fashion (Hirtle & Jonides, 1985; Rossano & Hodgson, 1994; Taylor, 2005), and qualitatively different types of map knowledge are acquired in a sequential, hierarchical order (Siegel & White, 1975). Research conducted in both real-world (Dogu & Erkip, 2000) and virtual reality (Darken & Sibert, 1996; Pausch, Burnette, Brockway, & Weiblen, 1995) settings has confirmed that environmental cues are important in the initial stages of map learning and navigation even though such cues may sometimes be ambiguous, resulting in navigational errors. The formation of cognitive maps can be influenced by a variety of factors such as general knowledge and expectations (e.g., Tversky, 1981), map format (e.g., Taylor, 2005; Thorndyke & Hayes-Roth, 1982), and goals (e.g., Taylor, 2005; Taylor, Naylor, & Chechile, 1999).

A key issue in map learning is the role of the cognitive mechanisms involved in the formation of mental maps. Some of the issues that have been researched in a map learning context include how testing during learning enhances memory (Carpenter & Pashler, 2007), and the impact of individual differences (e.g., Thorndyke & Stasz, 1980), such as visuospatial ability (Coluccia, Bosco, & Brandimonte, 2007; Coluccia, Iosue, & Brandimonte, 2007), in map acquisition. In many cases, the roles of these elements in map learning reflect their roles in related visuospatial tasks and can be generalized to complex learning. Nevertheless, a number of questions related to the cognitive underpinnings of map learning remain to be investigated, including a variety of issues relevant to procedural learning that offer the potential to produce further insights into map learning.

1.1.2. Retention of directions

Investigation of learning a series of directions for navigation has produced some initial principles that can be employed to optimize performance (see, for example, Allen, 1997, for a review). One of the questions previously addressed is which components of verbal directions promote effective recall (e.g., Reagan & Baldwin, 2006). Research has also shown that memory for a series of verbal directions is impacted by the complexity of the cognitive map to which they refer (Barshi & Healy, 2002). Barshi and Healy's work in particular highlights the interaction that occurs between memory for verbal information and the visual environment to which it refers in a navigation context.

1.2. Multimedia learning theory

One approach with the potential to enhance memory for maps and driving directions originates from research conducted principally in educational settings. The cognitive theory of multimedia learning posits that optimal learning occurs when the learner engages in the appropriate combination of visual and verbal thinking (see Mayer (2005) and Peeck (1994) for reviews). According to multimedia learning theory, optimal learning is not purely verbal or visual, but combines both types of information in the most effective way. Most research on multimedia learning has focused on teaching a series of facts (e.g., Rockwell & Singleton, 2007) or relating information to a central concept, such as how a bicycle pump works (Mayer & Anderson, 1991). Other research, perhaps more relevant to the demands of learning a series of directions for navigation, has examined learning of multimedia procedural information (e.g., Brunyé, Taylor, Rapp, & Spiro, 2006). For example, Brunyé and colleagues observed enhanced learning of a series of assembly instructions presented through a combination of pictures and text rather than through text or pictures alone. Thus, prior research supports the use of a multimedia learning approach to enhance learning of procedural and conceptual information.

Two aspects of multimedia learning theory relevant to the current experiment are the modality and contiguity principles. The modality principle maintains that presenting information in both the visual and verbal modalities results in enhanced learning, given that verbal information is presented orally (Mayer, 2002; Mayer & Anderson, 1991, 1992; Mayer & Moreno, 2003; Tindall-Ford, Chandler, & Sweller, 1997). Verbal information must be processed aurally because visual presentation of text causes attentional interference with visual stimuli, hindering learning. The contiguity principle maintains that presentation timing is just as important as modality, such that simultaneous presentation of integrated visual and verbal information results in improved problem-solving transfer (i.e., application of learned skills to a novel context) compared to sequential presentation (Baggett, 1984, 1989; Baggett & Ehrenfeucht, 1983; Mayer & Anderson, 1991). For example, Mayer and Anderson found that participants who watched a presentation with a step-by-step explanation of a concept presented in visual and verbal form simultaneously were better able to answer questions requiring the synthesis and application of explicitly taught concepts compared with participants exposed to sequential or single modality presentations. By way of explanation, Mayer and colleagues (Mayer & Anderson, 1991, 1992; Mayer, Moreno, Boire, & Vagge, 1999; Mayer & Sims, 1994) argue that simultaneous presentation promotes superior application of learned concepts by strengthening associations between related visual and verbal information, leading to enhanced learning and recall.

1.2.1. Ordering sequential information

Conjoint retention theory (Kulhavy, Lee, & Caterino, 1985), a complementary approach that offers an extension beyond the above principles, has focused on the influence of order of sequentially presented visual and verbal information on learning. This theory posits that greater interference occurs when verbal information is presented before related visual information, leading to impoverished learning. In learning information contained in an instructional passage supplemented with diagrams or concept maps, presentation of the visual aids prior to the text leads to superior recall compared with text-first presentation (Kulhavy et al., 1985; Verdi & Johnson, 1997). According to conjoint retention theory, the processing of verbal stimuli demands a greater amount of executive resources than the processing of visual stimuli, depleting the learner's attentional store before visual stimuli can be processed. In contrast, the processing of visual stimuli is comparatively less demanding, and these stimuli can serve as a guide, allowing the learner to effectively integrate verbal information into a pre-existing visual cognitive framework. Another reason why learning is enhanced when visual stimuli are presented prior to verbal stimuli is that reading or listening to a verbal description is especially meaningful when it can be related to a visual representation. Conversely, relating visual stimuli to abstract verbal representations does not improve learning because verbal information does not serve as an effective framework for interpretation.

Both multimedia learning theory and conjoint retention theory offer explanations of how the modal content and timing of instructional materials interact to affect learning. Given that many cognitive mechanisms involved in conceptual and procedural learning are also believed to play important roles in map learning and direction retention, these theories may be applicable to map learning and navigation.

1.3. Applying multimedia learning theory

The purpose of this experiment was to apply multimedia learning theory to the domain of map learning and navigation. In previous multimedia learning theory research, two types of instructional materials have been used: animation and narration. Although multimedia learning theory allows for the use of various types of instructional materials, for the current study, a map was used as the visual stimulus and narrative driving directions were used as the verbal stimulus. This format was selected to be consistent with previous temporally driven studies (e.g., Brunyé et al., 2006) and the intrinsic use of maps as a basis for driving directions in a real-world context.

In this experiment, five conditions consisting of information presented in various combinations were created to examine the impact of modality (visual or verbal; single or dual) and presentation timing (sequential or simultaneous) on map learning and navigation. Learning was assessed using both an explicit recall task, in which participants either wrote out directions or drew routes graphically, and a navigation task, in which participants navigated routes in a driving simulator. Both of these tasks drew upon route knowledge because participants were required to recall specific information pertaining to the routes that they had studied. Based on multimedia learning theory, it was hypothesized that participants exposed to dual modality (simultaneously or sequentially presented) instructional materials would demonstrate superior performance in both tasks compared with participants exposed to single modality instructional materials due to the presence of complementary visual (map) and verbal (narrative directions) information, which would strengthen cognitive associations within the information, thereby facilitating learning.

To parallel prior multimedia learning research, this experiment included a problem-solving transfer task, in which learned concepts were applied to a novel context. In order to successfully complete this task, participants were required to synthesize a novel route from elements of two studied routes by connecting the routes and inverting the pattern of turns for the second route. Although it could be determined from the instructional materials that the two studied routes interconnected, this fact was not overtly indicated in the presentation. Therefore, this task required participants to draw upon global knowledge in order to successfully manipulate and synthesize previously learned information in accordance with a novel goal. Based on the research of Mayer (2001), it was believed that participants exposed to simultaneous dual modality materials would demonstrate superior performance in the transfer task due to further strengthening and consolidation of cognitive associations within the information, producing the enhanced learning necessary to allow the application of learned information to a novel context.

2. Method

2.1. Participants and design

Sixty-five participants were recruited from the Colorado State University campus and compensated with either partial course credit or $10. Fifteen participants reported simulator adaptation issues (motion sickness) and did not participate in the experimental session. Data from one additional participant was eliminated due to a failure to follow task instructions.

Participants were randomly assigned to one of five presentation conditions (i.e., between-subjects design): map and narration presented simultaneously, map followed by narration, narration followed by map, map only, and narration only.

2.2. Materials

The driving simulator used in this experiment (a Drivesafety DS-600c system) was a fixed-base unit consisting of the front half of a Ford Focus automobile with a 180° simulated field of view surrounding the cab along with rearview and side view mirrors. No kinesthetic feedback was provided via the body or steering wheel of the simulator.

The schematic used to produce the virtual world in this experiment was created using the driving simulator operating system's map editor application. This schematic, designed to resemble a miniature city with outlying suburbs, consisted of a total of 23 intersections and was plotted on a 9-by-9 square grid. For conditions with a visual component, the map presented to participants was created based on the schematic by simplifying and labeling the elements depicted to more closely resemble an everyday map (see Fig. 1). To illustrate directions, animation of a line progressed along the routes (i.e., sections of the routes were highlighted). For conditions with a verbal component, narrative directions for each step of the routes (see Table 1) were recorded and played back using a sequence of digital audio files created with QuickTime Player.

Five fixed-pace PowerPoint presentations, each corresponding to one condition, were created by placing the animated route map and/or pre-recorded digital audio files on a series of slides ordered to represent the step-by-step directions for each route. Directions were created by dividing each route into seven roughly equal segments using intersections at which participants were required to turn as division points. All directions included at least two pieces of information, one of which was the terminal intersection for the relevant segment and the remainder of which, in most cases, consisted of a different type of information (landmark, street name, zone type, etc.), or else indicated other intersections. The total duration of the presentations used to teach both routes was equal across conditions at 48 s apiece.

2.3. Procedure

2.3.1. Pre-experiment exposure to simulator

All participants completed a 10-min simulator adaptation session held approximately 24 h, and no less than 12 h, prior to the experimental session. The purpose of this session was to allow participants to acclimate themselves to the driving simulator environment and practice simple maneuvers such as acceleration, deceleration, braking, and turns in two simplified environments. The first environment was a straight drive, and the second contained a series of left and right turns. This session also indicated whether participants were susceptible to motion sickness effects, and those who reported any potential symptoms did not return to complete the experimental task. We note that to the extent that variations in susceptibility to

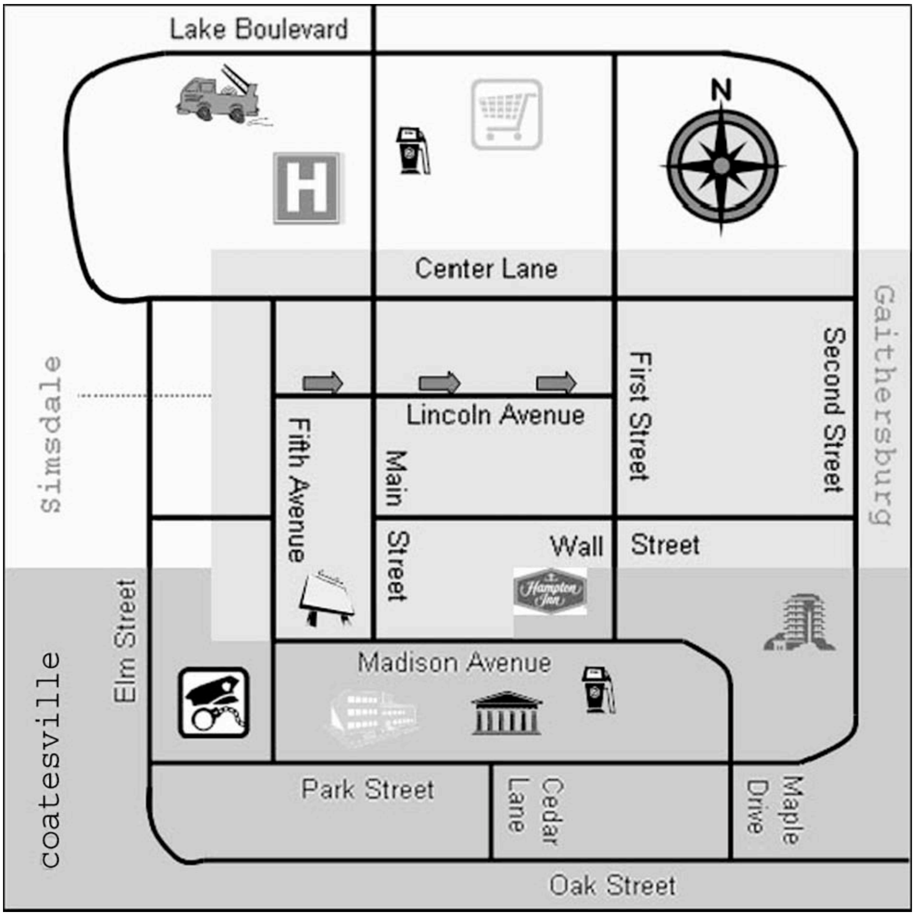

Fig. 1. Map from instructional stimuli reproduced in grayscale. (Original version of map used in experiment was in color.)

Table 1
Verbal Directions Used in Instructional Stimuli

Route 1	Route 2
1. You will begin on Oak Street in the Coatesville residential community to the southeast of Gaithersburg. Go straight for two blocks, passing through the first intersection.	1. You will begin on Main Street in the Simsdale industrial sector to the north of Gaithersburg. Go straight through the first intersection.
2. Take a right at the second intersection onto Cedar Lane.	2. You will now enter northern downtown Gaithersburg. In one block, take the first left after the hospital onto Center Lane.
3. Take a left at the next intersection by the university onto Park Street.	3. After one more block, take a right at the first intersection onto First Street.
4. In one block, turn right at the police station onto Fifth Avenue.	4. Continue straight past the next two intersections.
5. You will now enter southern downtown Gaithersburg. Take the first right onto Madison Avenue.	5. Take a right onto Madison Avenue at the third intersection by the Hampton Inn.
6. On your left, you will see a billboard. Immediately afterwards, take a left onto Main Street.	6. Go straight for two blocks, passing through the first intersection.
7. Take the first right onto Wall Street. Your destination is the first intersection that you encounter.	7. Turn right onto Fifth Avenue at the second intersection after passing the billboard on your right. Your destination is the first three-way intersection that you encounter.

simulator adaptation may not be random, elimination of participants for this reason may create some potential issues for generalizing the findings to all members of the population.

2.3.2. Experimental session

Experimental sessions lasted approximately 45 min. Each session consisted of four parts: a study segment, a recall segment, a navigation segment, and a problem-solving transfer segment. In the study segment, participants watched the PowerPoint presentation corresponding to their assigned condition, which conveyed two routes contained within the same geographical area. Participants were instructed to memorize the routes because they would be asked to recall them later. After the study segment, participants completed a 60-s distracter task, in which they listed US state capitals, to ensure that the information recalled later was based in long-term memory.

In the recall segment, participants were instructed to list the key elements of the directions for both routes that they had studied in the order in which they were presented. These instructions were intentionally left ambiguous so that participants could choose to represent the routes either graphically or verbally. The purpose of providing ambiguous task instructions was to reduce the possibility of disparities in performance due to an interaction between task demands specifying that recall be visually or verbally based and the presence or absence of material presented in the corresponding modality in the instructional stimuli. After the recall task, participants completed another 60 s of the distracter task to remove the route directions from working memory again.

In the navigation segment, participants maneuvered the driving simulator through the virtual world represented by the map and/or verbal directions presented in the instructional stimuli, once for each route, to demonstrate localized route knowledge. They were instructed to follow the directions that they had studied, but to try to reach the destination point of each route even if they had forgotten any of the directions. Participants were instructed to drive as they would normally and obey all traffic laws. A speed limit of 35 miles/h was posted in an attempt to minimize interference due to speeding. The navigation segment ended when participants had either reached the destinations of both routes successfully or when a 7 min time limit for each route had elapsed.

Finally, in the problem-solving transfer segment, participants were instructed to drive from the starting point of the first route to the ending point of the second route to test abstract, global knowledge of the area. As in the navigation segment, participants were instructed to attempt to find the destination even if they could not generate the individual steps of the route, and again a time limit of 7 min was enforced. Additionally, obstacles (i.e., permanent cement barriers) were placed on roads that formed the side boundaries of the area to prevent participants from following the perimeter to reach the end-point, which was located on the side opposite the starting point. When participants had successfully reached the destination or the time limit had elapsed, the task was complete. At this point, the experimental session ended, and participants were debriefed about the purpose of the study.

2.4. Measures

Five different measures were used to assess various aspects of learning. The first issue of interest concerns the relative success of the groups in memorizing the studied routes. Performance in the recall task was indexed as the total number of turns recalled correctly for each route. In order for a turn to be considered accurate for the purposes of this task, participants were required to state the direction of the turn and provide either sequential information (i.e., correct sequence of turns or verbal specifiers such as "second") or localizing information (i.e., landmarks, street names, or cardinal directions). Turns were judged on an item-by-item basis so that route totals represented an overall measure of performance. Totals for each studied route were combined together into a single, overall score for recall. The maximum possible number of correct turns for each route was seven, summing to a total of 14 possible correct turns for both studied routes.

The next question addressed was whether differences in memory for driving directions between presentation groups were apparent in the driving task. Similar to the recall task, performance in the navigation task was measured by counting the total number of turns navigated correctly. Turns did not need to be navigated consecutively in order to be counted as correct; hence, participants departing from the designated route but later returning to it were scored with correct performance for any sections of the route correctly followed. The maximum possible number of correct turns was 25 in total, consisting of a subtotal of 14 correct turns for the two studied routes (seven per route) and a subtotal of 11 correct turns for the novel transfer task route.

The next measures examined ability to synthesize learned information to produce a novel route. Performance on the novel route was indexed in terms of two metrics. One measure assessed the efficiency of the route the participants generated, indexed as time to reach the end of the route, or in the case of failure to reach the destination, the score was indexed as the maximum 7 min allowed. A second measure concerned how successful the novel route generated was, recorded as a binary score indicating whether participants reached the endpoint of the route.

The final measure indicated global navigation success by examining how many of the three destination points (two studied routes + one novel transfer task route) the participants reached within the time limit imposed for each task.

3. Results

Predictions from the hypotheses outlined above were examined through appropriate comparisons using planned contrasts. To maximize power, no correction to the criterion for individual comparisons was employed, despite some associated risk of an inflated Type I error. For completeness, the results reported here also include an initial omnibus test result and overall effect size.

3.1. Recall of studied routes

The first set of analyses examined recall for the two studied routes, determining whether there were differences in memorization of directions. There was an overall effect of condition ($F(4,44) = 4.19$, $p < .05$, MSE = 8.59, $\omega^2 = .20$; see Fig. 2). A planned comparison showed a 107% benefit for the presence of a map in the instructional stimuli ($F(1,44) = 16.08$, $p < .05$). Likewise, a second contrast showed a 38% benefit for recall under dual modality conditions compared to single modality conditions ($F(1,44) = 6.80$, $p < .05$). There was no evidence from the recall test that learning via simultaneous presentation of dual modality stimuli differed from sequential presentation of dual modality stimuli ($F(1,44) < 1$). For participants receiving sequential presentation of the map and verbal narrative directions, there was no evidence that order of presentation (map then narration vs. narration then map) made a difference affecting recall ($F(1,44) < 1$). Overall, these data suggest that the presence of a map in instructional materials facilitates recall of studied routes, and because the contrasts were not orthogonal, this effect was also associated with a weaker apparent overall effect of modality.

3.2. Navigation of routes

The next set of analyses examined participants' ability to follow the studied and novel routes within the simulator (i.e., number of turns navigated correctly). There was no overall effect of condition ($F(4,44) = 1.47$, $p > .05$, MSE = 20.90, $\omega^2 = .04$; see Fig. 3). However, a planned comparison showed a 75% benefit for driving performance under dual modality conditions

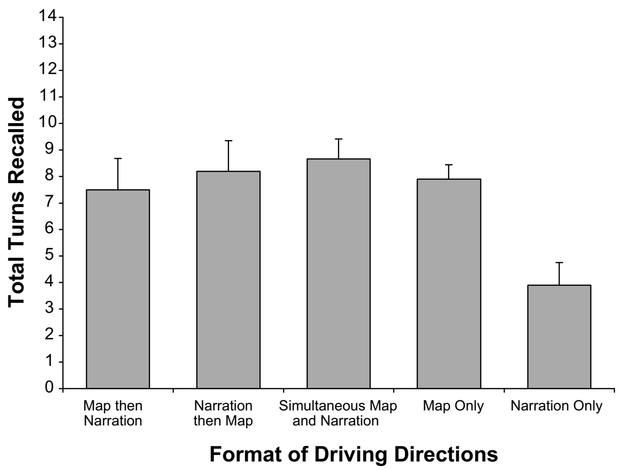

Fig. 2. Mean number of turns recalled correctly for both studied routes by presentation condition. (Error bars represent standard error.)

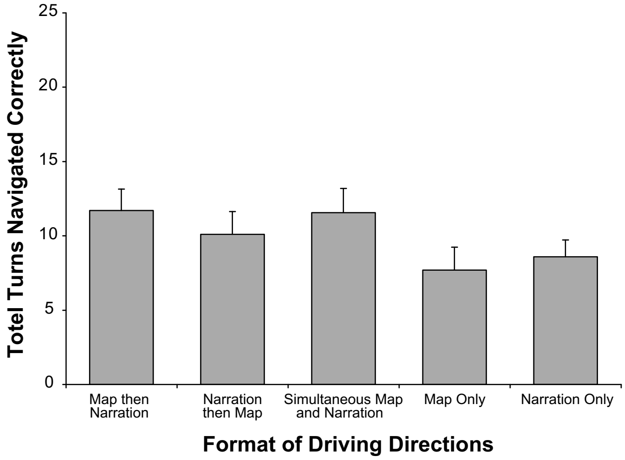

Fig. 3. Mean number of turns navigated correctly for all three routes by presentation condition. (Error bars represent standard error.)

compared with single modality conditions ($F(1,44) = 4.98$, $p < .05$). As with the recall test, there was no evidence that learning under dual modality simultaneous presentation of stimuli differed from learning under dual modality sequential presentation of stimuli ($F(1,44) < 1$). For sequential presentations of the map and narrative directions, there was again no evidence that order of presentation (map then narration vs. narration then map) differentially affected ability to follow routes ($F(1,44) < 1$). Finally, unlike the recall task, a planned comparison showed no evidence of a general advantage for driving performance under study conditions containing a map ($F(1,44) = 1.05$, $p > .05$). These results provide evidence that dual modality instructional materials promote navigational accuracy.

3.3. Navigation of novel route

Analyses next examined participants' ability to generate a novel route by synthesizing elements of the two studied routes. The first set of analyses focused on time to reach the destination of the novel route or termination of the run. There was no overall effect of condition ($F(4,44) = 1.47$, $p > .05$, MSE = 4107, $\omega^2 = .04$; see Fig. 4). Planned comparisons showed no evidence to support differences in performance under dual modality conditions compared with single modality conditions ($F(1,44) = 1.19$, $p > .05$), no effect of map presence during study ($F(1,44) < 1$), and no effect of simultaneous versus sequential presentation of dual modality stimuli ($F(1,44) = 1.13$, $p > .05$). However, in accordance with the predictions from conjoint retention theory, a 13% trend in favor of less time spent to reach the destination of the novel route was observed for participants who were exposed to the map prior to the verbal narration compared with participants who were exposed to the narration prior to the map ($F(1,44) = 3.63$, $p = .06$). This trend suggests that presentation of a map prior to narrative driving directions may assist in mental consolidation of learned information, resulting in a slight increase in efficiency in the problem-solving transfer task.

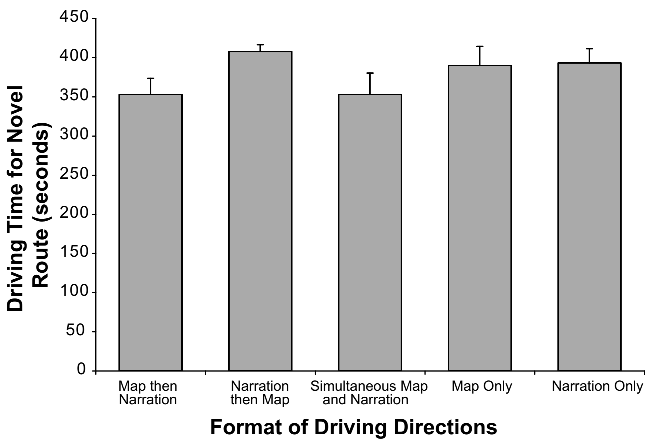

Fig. 4. Mean time spent driving (in seconds) for novel transfer route by presentation condition. (Error bars represent standard error.)

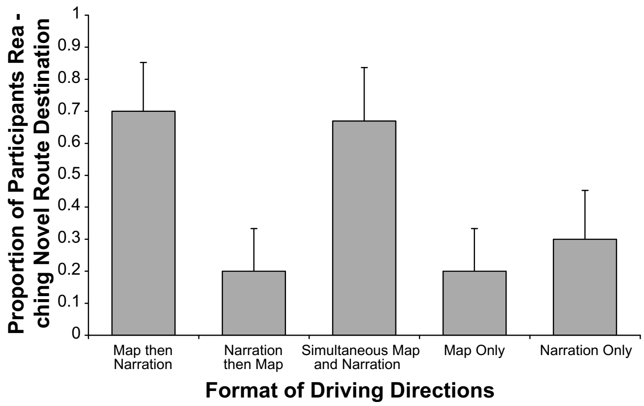

Fig. 5. Proportion of participants reaching destination of novel transfer route by presentation condition. (Error bars represent standard error.)

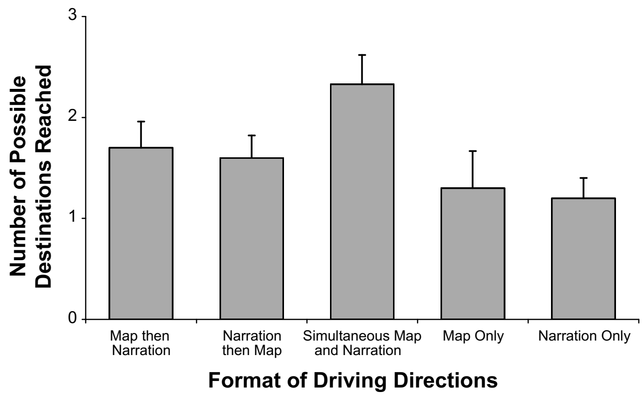

Fig. 6. Mean number of destinations reached for all three routes by presentation condition. (Error bars represent standard error.)

The second set of analyses examined whether the destination of the novel route was successfully reached. For this measure, there was an overall effect of condition ($F(4,44) = 2.44$, $p < .05$, MSE = .214, $\omega^2 = .13$; see Fig. 5). A planned comparison showed a 109% benefit for reaching the destination under dual modality conditions compared with single modality conditions ($F(1,44) = 4.10$, $p < .05$). A 250% benefit was also observed for participants who were exposed to the map prior to the verbal narration compared with those exposed to the narration prior to the map ($F(1,44) = 5.85$, $p < .05$). Once again, there was no effect of map presence during study ($F(1,44) < 1$) and no effect for simultaneous versus sequential presentation of dual modality stimuli ($F(1,44) = 1.36$, $p > .05$). These results provide further evidence that dual modality instructional materials facilitate navigation and also indicate that map-first presentation order can enhance wayfinding in a novel context.

3.4. Total destinations reached

The final set of analyses determined whether participants reached the destinations of all three routes before the time limits expired. For this measure, there was a marginal overall effect of condition ($F(4,44) = 2.54$, $p = .05$, MSE = 0.732, $\omega^2 = .11$; see Fig. 6). A planned comparison showed a 50% advantage of dual modality conditions over single modality conditions in allowing participants to reach route destinations ($F(1,44) = 6.37$, $p < .05$). Another contrast showed a 41% advantage for simultaneous compared with sequential presentation of dual modality stimuli ($F(1,44) = 3.96$, $p = .05$). In comparing the order of stimuli in sequential presentations with a map and verbal narration (map then narration vs. narration then map), there was no evidence of a difference ($F(1,44) < 1$). Additionally, no difference was observed between conditions with a map and the narration-only condition ($F(1,44) = 3.09$, $p > .05$). These results provide additional verification that dual modality study materials enhance wayfinding while also suggesting that presentation timing can affect global navigation success.

4. Discussion

Overall, the results of this experiment support the applicability of the modality principle of multimedia learning theory (Mayer, 2002; Mayer & Anderson, 1991) to a novel context: map learning and navigation. Performance on the recall and navigation tasks demonstrated that multimedia instructional materials enhance memory for and application of studied information. In contrast to the clear advantages of using dual modality instructional materials, simultaneous presentation of visual and verbal materials showed only a general trend in favor of reaching a greater number of destinations overall. Thus, evidence that could be interpreted as support for the contiguity principle of multimedia learning theory (Mayer & Anderson, 1991; Mayer & Sims, 1994) is far more limited than evidence supporting the modality principle. The results are, therefore, only partially consistent with the hypothesis that simultaneously presented dual modality stimuli would promote effective map learning and navigation.

4.1. Visual representation and map learning

Superior performance on the recall task under conditions with a map suggests that visual representation facilitates recall of visuospatial information. This observation is consistent with a long history of such effects, including evidence from Paivio's (1971, 1986) dual-coding theory. The present findings also provide some support for conjoint retention theory (Kulhavy et al., 1985) by suggesting that visual stimuli can act as a guide for the interpretation and consolidation of verbal material, thereby enhancing the function of instructional materials, with these effects emerging when participants were required to generate a novel route by synthesizing learned information. Stated differently, these results suggest that displaying visual materials prominently during instruction will facilitate the acquisition of accurate cognitive maps, which in turn will facilitate navigation, even when applied to a novel route.

Results of the recall task are generally consistent with prior research concerning direction retention. The mean number of correct turns recalled for both routes was 7.2 across all conditions, resulting in an average of 3.6 correct turns per route. This figure is generally consistent with Barshi and Healy (2002), who found that even in short-term memory, recall of directions for navigation composed of three units of information (with each unit comprising the equivalent of a direction and a distance) was reasonably accurate but deteriorated drastically for directions composed of four or more units. Nevertheless, the mean number of correct turns for both routes increased to 9.9 for the navigational accuracy measure (an average of five correct turns per route), diverging somewhat from Barshi and Healy's results. This difference could be due to cues from the comparatively rich environment used in the current experiment (Barshi and Healy's comprised three grids of squares with no other features present), binary choices for route selection at some junctions improving the odds from guessing compared with free recall, and/or inclusion of landmark information in the directions.

4.2. Multimedia learning theory and driving performance

The benefit of dual modality instructional materials on the number of turns correctly navigated and destinations reached in the driving navigation and problem-solving transfer tasks provides support for the modality principle of multimedia learning theory. This principle maintains that optimal learning occurs when material is presented in the appropriate combination of visual and oral verbal forms due to the strengthening of cognitive associations within learned information.

The greater overall number of destinations reached by participants assigned to the simultaneous dual modality condition provides limited evidence supporting the contiguity principle of multimedia learning theory, which maintains that simultaneous presentation of dual modality instructional materials leads to improved performance in problem-solving transfer tasks, in which learned information is applied to a novel context (Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994; Mayer et al., 1999). However, this measure differs from measures used in previous multimedia learning experiments in that the number of destinations reached is a generalized indicator of success rather than a pure measure of problem-solving transfer. In addition, the demands of generating a novel route between two endpoints probably draws more heavily upon global survey knowledge than localized route knowledge (see Thorndyke & Hayes-Roth, 1982). Simultaneously presented dual modality information may jumpstart the map learning process by effectively conveying global information, which is typically acquired before local information in maps (Hirtle & Jonides, 1985; Rossano & Hodgson, 1994; Taylor, 2005). It is also possible that the design of this experiment may have encouraged participants to rely upon global map knowledge because they were instructed to try to reach the route destinations even if they could not remember the directions, perhaps exaggerating effects at the global level. It is certainly plausible that a different pattern of results would have emerged if local map knowledge had been tested via such means as directing participants to find sub-destinations for each route.

Performance on the problem-solving transfer task provided partial support for the claims of both conjoint retention theory and multimedia learning theory. In accordance with conjoint retention theory, participants were more likely to reach the destination of the novel route in slightly less time under the map-first sequential condition than under the narration-first sequential condition. Conjoint retention theory and related theories posit that presentation of visual material prior to verbal material helps participants form an initial cognitive framework for interpretation that is supplemented by subsequently presented relevant verbal information, resulting in enhanced learning. Consistent with the modality principle of multimedia learning theory, participants were also more likely to reach the destination of the novel route if they had been exposed to dual modality rather than single modality instructional materials in the study task. Nevertheless, future research is needed to clarify the role of dual modality instructional materials in promoting the application of learned material to a novel context within the realm of driving navigation.

Overall, the results of this experiment suggest that the general principles of multimedia learning theory offer valuable insights for improving the learning of maps and driving directions, but some differences from conclusions based on research in other domains may exist. These findings can be applied to improve the conveyance of navigational information via aids such as interactive maps and, potentially, the type of information available for download to PDA's and smartphones from online navigational websites, thereby allowing users to take advantage of underlying cognitive processes to promote optimal accuracy and efficiency in map learning and driving navigation.

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