Repetition and Dual Coding in Procedural Multimedia Presentations

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SUMMARY

Students learned toy assembly sequences presented in picture, text, or one of three multimedia formats, and completed order verification, recall, and object assembly tasks. Experiment 1 compared *repetitious* (i.e. dual format presentations each conveying similar information) with *complementary* (i.e. dual format presentations each conveying different information) multimedia presentations. Repetitious presentations appear to provide learning benefits as a function of their inherent redundancy; complementary presentations provide benefits as a result of users actively integrating picture and text elements into a cohesive mental model. Experiment 2 compared repetitious with *interleaved* (i.e. assembly steps presented in alternating picture-text formats) multimedia presentations. Again, multimedia presentations led to overall learning advantages relative to single-format presentations, with an emphasis on both repetition and integrative working memory processes. Object assembly performance consistently demonstrated the utility of picture learning, with or without accompanying text. Results are considered relative to classic and contemporary learning theory, and inform educational design. Copyright © 2007 John Wiley & Sons, Ltd.

Success in building an object or system, such as assembling a bicycle or computer network, is contingent upon well-designed instructions. Effective instructions help individuals learn about the elements of a procedure, as well as the connections and relationships between those elements; they are, in effect, lessons in how to perform a particular task (Zacks & Tversky, 2003). The present experiments examine the role of pictures and text in instructional presentations to gain insight into what presentation formats and organizations promote an understanding of how to successfully construct multi-step projects. In particular, we compare the effectiveness of different multimedia combinations (i.e. pictures with accompanying texts) to single-format (i.e. picture- or text-only) presentations on the comprehension and learning of procedures, and performance outcomes for completing assembly tasks.

A growing body of evidence supports multimedia effectiveness for conveying both procedural instructions (Brunyé, Taylor, Rapp, & Spiro, 2006; Diehl & Mills, 1995; Glenberg & Langston, 1992; Marcus, Cooper, & Sweller, 1996; Stone & Glock, 1981;

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Zacks & Tversky, 2003; but see Novick & Morse, 2000) and declarative information (e.g. Levie & Lentz, 1982; Mayer, 1989, 1997, 2001; Mayer, Bove, Bryman, Mars, & Topangco, 1995; Mayer & Gallini, 1990; Peeck, 1994; Sweller, 1999). Multimedia shows clear learning benefits as compared to text alone (see Levie & Lentz, 1982 for a review), and in some cases pictures alone (e.g. Brunyé et al., 2006; Gyselinck, Cornoldi, Dubois, De Beni, & Ehrlich, 2002; Stone & Glock, 1981).

One influential evidence-based account of multimedia benefits is suggested by Mayer's (1997) *Generative Theory of Multimedia Learning*. This theory is rooted in classic and contemporary memory theory, most notably Paivio's (1986) *Dual Coding Theory* and Baddeley's (1992) *Working Memory Model*. The notion is that multimedia presentations are especially effective for learning because they involve both spatial and verbal working memory, or rather because individuals need not focus all of their processing on a single format. Partitioning working memory across multiple presentation formats appears to increase flexibility of a learner's experience and to be particularly effective at freeing up cognitive resources for deeper information processing (Paas, Renkl, & Sweller, 2003; Van Merrienboer, Kirschner, & Kester, 2003). In fact, there is evidence that such partitioning aligns directly with deeper processing in a fairly intuitive way: integrating spatial and verbal information is in and of itself a form of deeper processing (Mayer, 1997; Mayer & Moreno, 2002): Because descriptions (text or narration) and depictions (images or animation) are processed by separate memory subsystems (i.e. Brunyé et al., 2006), individuals can (and sometimes must) actively process and integrate such information. Throughout this paper, we will refer to this process of linking multimedia's spatial and verbal information within working memory as '*active integration*'. The process is active in the sense that it requires learners to actively select pieces of information from a presentation (i.e. Mayer, 1997); it is integrative in the sense that learners build associative links (i.e. Paivio, 1986) between perceptually disparate spatial and verbal information to form a single, abstracted and cohesive mental representation.

Recent work in our laboratory (Brunyé et al., 2006) has demonstrated central executive involvement towards the active integration of spatial and verbal information during multimedia learning; in a series of dual-task experiments participants learned single format (picture only and text only) and multimedia (picture and text) assembly sequences while undertaking one of six working memory tasks designed to interfere with articulatory, visuospatial, central executive, or sequencing resources. Performance on several memory tasks demonstrated a multimedia advantage relative to both single-format presentation types, and an advantage of pictures relative to text. Further, performance patterns demonstrated clear roles for articulatory resources in processing textual presentations, visuospatial resources for images and central executive resources when the text and pictures were combined into multimedia. Multimedia thus appears to be an effective format for learning assembly sequences that demands the involvement of multiple working memory systems, including the central executive, perhaps towards active integration.

One alternative explanation for multimedia effectiveness is that the picture/text components comprising multimedia may provide repetitious information, which does not necessarily require integration to produce learning advantages. For example, informal reviews of several scientific texts (e.g. Carlson, 2001; Kalat, 2003; Smith, 1992) as well as assembly instructions for everyday items (e.g. bicycles, model airplanes and rockets) reveal obvious cases in which images and text present roughly equivalent information. Often this repetition was exemplified by images with text captions that briefly summarized portions of image content, while in other cases the images were accompanied by explicitly

repetitious and relatively lengthy descriptions. These combinations allow for the possibility that any active integration-based benefits, as suggested by dual coding (Mayer, 1997), could be explained by repetition (e.g. Levie & Lentz, 1982).

Levie and Lentz (1982) have suggested that repetition may account for learning advantages when illustrations accompany text. In contrast, Sweller's cognitive load theory (1988, 1999) suggests that repetition may actually increase working memory load and negatively impact learning, ultimately as a function of reduced integration into long-term memory. Thus, in one sense repetition may be beneficial, in the other sense it may detract from learning. Despite the potential role of repetition, multimedia research has not specifically compared repetitious (i.e. repeating similar information across formats; Levie & Lentz, 1982) versus complementary (i.e. providing different information across formats; Mayer, Hegarty, Mayer, & Campbell, 2005) presentations.

The present experiments extend prior work in our laboratory (i.e. Brunye, Taylor, & Rapp, 2003; Brunyé et al., 2006) and fill this research gap by examining the utility of repetitious versus complementary multimedia towards learning procedural sequences. Repetition in multimedia is found, for example, when a picture and text convey the same gist information relevant to a task goal. Figure 1a is a good example of this: the picture depicts the final step of the procedural sequence 'Assembling a Snoopy on Skis', which involves attaching the skis to the body; similarly, the text describes this same operation. To the extent that the picture and text convey the same gist information needed to complete a task goal (i.e. attach the skis to the body), we consider them repetitious. Complementary multimedia, in contrast, does not provide this repetition, and should promote active integration because complete information cannot be derived from any single format. Figure 1b is a good example of this: the picture depicts the item *to be attached* during the fourth step of the procedural sequence (the skis); the text tells the learner *what to do* with the depicted item. To the extent that pictures and text necessitate a switching between formats to acquire information relevant to a task goal, we consider them complementary. Comparing the effectiveness of repetitious and complementary multimedia allows an evaluation of repetition and active integration's separable contributions to multimedia comprehension (Mayer, 1997; 2001), which to date have not been delineated. This comparison can also provide insight into conditions that underlie the potential positive (e.g. Levie & Lentz, 1982) or negative effects (e.g. Sweller, 1988, 1999) of repetition.

To test issues of repetitious vs. complementary information and active integration, we conducted two experiments. Experiment 1 was designed to test the influences of repetition and active integration on learning assembly procedures using two types of multimedia—

(A)

4. Attach the top of the skis to the bottom of the body, with the curved tip of the skis facing forward.

(B)

4. Attach the pictured item to the bottom of the body, with the curved tips facing forward.
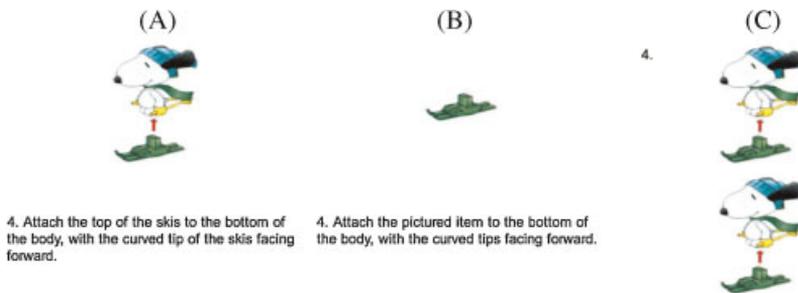
(C)

4.

Figure 1. a–c: A sample sequence step in repetitious (a) and complementary (b) multimedia formats, as well as a step from the picture-only comparison condition in the repetitious group (c)

repetitious (each format conveys gist-equivalent information) and complementary (each format conveys different information)—and comparing them to picture- and text-only formats. Experiment 2 further explores active integration by investigating the relative effectiveness of interleaved (sequence steps alternating between picture and text formats), as compared to conventional (repetitious) multimedia. Both studies allowed us to assess the role of active integration, as well as the conditions that may foster it, during multimedia experiences.

EXPERIMENT 1

Our first experiment examined the influences of repetition and active integration on learning procedures from multimedia. To obtain an overview of their influences, we examined basic memory and source memory for procedures, as well as the ability to complete the procedures in object assembly. The methodology and stimuli were of critical import in the design of our study. First, we needed an assembly task that would be tractable in an experimental environment as well as naturalistic. We selected Kinder Egg^{TM} toy assembly sequences, which are chocolate treats containing plastic eggs holding a small toy as a prize. Many of these toy prizes require assembly; they are composed of multiple puzzle-like pieces and include illustrated, multiple-step instructions showing how to build the toy. While the toys appear simple, in many cases, failing to follow the steps in the prescribed order can lead to problems in successfully building the toy.

Second, we needed to develop stimuli that included both single-format presentations (i.e. in text or pictures only), as well as two types of multimedia stimuli (i.e. including both texts and pictures): repetitious and complementary. Building these materials is challenging, particularly since it is impossible to establish complete informational equivalence across formats (see Schnotz, 2001). However, note that for two of our memory measures (order verification and recall), perceptual equivalence is not as important as what we term 'gist' equivalence. That is, the appropriate operation (e.g. attach the skis to the body) is easily derived from both pictures *and* text, despite their perceptual and symbolic inequality. Critically, our dependent measures were concerned with memory for these operations and their order, and not the additional details included in the pictures (e.g., bright colours, cartoon-like figures, object orientations). Kinder Egg^{TM} toys come with pictorial instructions. We approached the challenge of creating text instructions by asking pilot participants to generate verbal materials for each step of the Kinder Egg^{TM} pictorial sequences. The resulting descriptions were combined and normed to create the verbal materials. Repetitious multimedia presented these text instructions combined with the original Kinder Egg^{TM} pictures, thus presenting gist equivalent information in both formats (as determined through pilot testing; Brunyé et al., 2006). Complementary multimedia presented pictures and texts that did not overlap in content, making both necessary for complete comprehension. Single format (picture- or text-only) presentations served as comparison conditions.

Our dependent measures tested both memory and assembly performance: free recall (declarative knowledge), sequence order verification (temporal knowledge), format recall (source knowledge) and object assembly (procedural knowledge). The active integration necessitated by complementary multimedia should impart substantial learning benefits relative to single-format presentations. We hypothesized that multimedia advantages on measures of declarative and temporal knowledge would be due to an effect of the active and

simultaneous integration of picture and text information. With respect to the role of repetitious materials, we expect repetitious multimedia to impart memory advantages relative to complementary multimedia and both single-format types (in line with classic repetition effects; e.g. Ebbinghaus, 1885). This prediction contrasts Sweller's notion that repetition may increase cognitive load and decrease integration into long-term memory (e.g. Sweller, 1999).

Finally, we were interested in the degree to which multimedia advantages are phenomenologically experienced by learners. Because participants would see several single-format and multimedia presentations across the course of the experiment, we investigated the degree to which they encoded the format of the presentation. Recent work has demonstrated that individuals often misremember multimedia presentations as picture only (Brunyé et al., 2006), despite benefiting from the addition of text, as compared to picture-only materials. This finding demonstrates that while multimedia presentations may be misremembered as picture-only, participants *are* in fact studying both formats as reflected in an overall memory advantage. During multimedia learning participants appear to have and self-report having an attentional focus towards pictures during multimedia learning, and/or develop image-based internal representations. In the current study, we predicted that these source errors would be particularly high for complementary multimedia, because this format forces learners to actively switch between formats, perhaps increasing the chance of confusion regarding the original learning circumstances.

METHOD

Participants and design

Fifty-two Tufts University undergraduates participated for partial course credit. We incorporated a mixed design with multimedia type as a between-participant factor (2 levels: repetitious, complementary), and presentation format as a within-participant factor (3 levels: multimedia, picture-only, text-only). Twenty-seven participants received repetitious multimedia assembly sequences, and 25 received complementary multimedia sequences. Each participant group additionally viewed assembly sequences in picture- and text-only comparison conditions that did (repetitious multimedia group) and did not (complementary multimedia group) account for repetition effects. Specifically, single format comparison conditions in the repetitious multimedia group depicted (as picture-only) or described (as text-only) each sequence step twice in a step to control for repetition effects, while single format comparison conditions in the complementary multimedia group depicted or described each sequence step only once.

Materials and apparatus

The assembly sequences were adapted from 21 Kinder Egg[TM] toy assembly instructions, 18 to be learned in the primary phase of the experiment, and three additional sequences for toy assembly. The sequences varied in object category (e.g., animals, plants, vehicles, household items), assembly complexity (e.g., attaching skis to a body versus attaching an axel shaft to a vehicle undercarriage) and temporal order necessity (e.g., certain parts must be attached prior to subsequent parts). Each sequence included five steps, with the fifth always being the completed product.

All sequences were presented via SuperLab, in a randomized (within block) and counterbalanced (across blocks) manner, at 300×300 pixel resolution, with 14-point Times New Roman font. Repetitious and complementary multimedia always presented the pictures above the corresponding text, one step at a time. Single format comparison conditions varied in accordance with the multimedia groups to control for repetition effects. Specifically, single format comparison conditions (i.e., picture- and text-only) within the repetitious multimedia group repeated each step simultaneously on the screen (i.e., picture above picture, or text above text), as depicted for the picture-only format in Figure 1c. This single-format repetition controlled for the repetition inherent in repetitious multimedia. In contrast, single format comparison conditions to complementary multimedia showed each step only once (i.e. one picture, or one text passage), as in this case it was not necessary to control for repetition.

The dependent measures examined memory and assembly performance for the sequences. A free recall task (paper-based) presented participants with six recall sections (one per assembly sequence, per block), each containing spaces to write down both the sequence steps and the title. The order verification task (computer-based) presented trials depicting two steps of a sequence in either correct (half of all trials) or reverse (half of all trials) order. Participants determined whether a trial presented steps in the correct temporal sequence, from left to right (e.g. Brunyé et al., 2006; Glenberg & Langston, 1992). Participants were instructed that correct temporal order did not require contiguity; that is, a verification trial showing steps 2 and 4 would be considered in correct temporal order, despite the absence of step 3. The entire order verification task included ten trials for each learned sequence, five in picture-only and five in text-only format. All picture-only trials used images slightly modified from the original sequences to prevent participants from relying on unfolding completeness cues (i.e. looking for more 'complete' objects as they moved from left to right in the sequence). This modification involved showing the critical item of each step (e.g. Snoopy's skis) being attached to the otherwise fully assembled toy (e.g. Snoopy on skis), rather than the partially completed object, at every tested step. We measured accuracy and response time to each trial. Note that we only included single-format (picture- or text-only) and never multimedia trials on the order verification task; this was done for several reasons: First, we were interested in the extent to which order verification performance could be predicted by transfer-appropriate processing. For instance, memory representations following text-only learning may be best-suited for text testing trials relative to picture trials; similarly, multimedia learning may be more flexible at test than the representations following single-format learning. Using multimedia test trials would not allow us to determine which test format resulted in any increased task performance. Second, we hoped to gain insight into the form of memory representations following single- and dual-format learning; for instance, relative flexibility following picture-only or multimedia learning (but not text-only learning) might provide insight into the inherent abstractness of these formats' resulting representational forms. Finally, we intended to lessen the possibility of (re)learning during the order verification task: had we used multimedia test trials they would present, for instance, previously learned textual information along with the corresponding picture—any subsequent performance following text-only learning would undoubtedly be affected by picture exposure (Brunyé et al., 2003).

The format recall task (paper-based) listed the 18 sequence titles, and participants circled the format in which they had learned each sequence (i.e. picture-only, text-only, or pictures and text); performance on this task was measured using proportion recall. Finally,

object assembly involved three containers, each holding a single dissembled Kinder Egg[TM] toy; we measured accuracy and assembly time for each toy. Details regarding each dependent measure are further described below in the *scoring* section.

Procedure

Each participant sat at a computer and followed on-screen instructions guiding them through three learning and testing blocks, each presenting and testing on six unique assembly sequences—two picture, two text and two multimedia, presented in random order. The manner by which the 18 sequences were organized into the three blocks, as well as the formats in which they were presented, were counterbalanced across participants. All sequences began with a text title (e.g. 'Assembling a Snoopy on Skis') presented for 5 seconds, immediately followed by the five sequence steps, presented for 10 seconds each. At the end of each learning block (i.e. after learning six sequences) participants completed the free recall and order verification tasks.[1] The self-paced free recall task required participants to recall each of the six sequence titles and respective steps. Immediately thereafter, participants completed the self-paced order verification task, in which they were presented with 60 randomly presented trials (10 per sequence: 5 picture comparisons and 5 text comparisons) and were asked to decide whether the two steps appeared in the correct order from left to right. Participants responded to each trial by pressing keys labeled YES (C) or NO (M), and accuracy and response time were recorded. After three learning and testing blocks (18 sequences), participants completed the self-paced format recall task.

Finally, the object assembly task involved learning three additional sequences, one in picture-only, one in text-only and one in multimedia, presented in random order, and counterbalanced across participants for which sequences appeared in which format. We did not test object assembly performance for all 18 sequences to avoid introducing carry-over effects across our other dependent measures. Participants were instructed to assemble each toy as quickly and accurately as possible, while also conforming to the original sequence order. Object assembly was self-paced and performance was recorded using a digital video camera.

RESULTS

Scoring

Each free recall was scored for one measure: per cent correct of the four possible steps. The order verification data were collapsed across trials for each condition (picture-only, text-only, multimedia) and group (repetitious, complementary), and data were collected for both response time and accuracy. Format recall data were scored by computing the average occurrence of six possible error types, denoted as original format—misattributed format (picture-text, picture-multimedia, text-picture, text-multimedia, multimedia-text, multimedia-picture). The object assembly videos were scored in four ways: average assembly time (in seconds), number of assembly errors (e.g. attaching the skis in the wrong location), number of assembly order errors (e.g. attaching the skis before the hat) and number of corrections (e.g. removing the skis from the wrong location and correctly attaching them).

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[1]Based on pilot data, this testing order minimizes recall advantages potentially accrued from observing the order verification task prior to recall (which can be particularly problematic after text-only learning; Brunyé et al., 2003).

Error correction and step reversal data were minimal and therefore not included in subsequent analyses.

Analysis

To confirm the utility of separate analyses by our four dependent tasks, a single 2(multimedia type: repetitious, complementary) × 3(presentation format: pictures, text, multimedia) × 4(dependent task: free recall, order verification, format recall, object assembly) omnibus ANOVA was conducted; results confirmed a significant presentation format by dependent task interaction, $F(6, 300) = 32.437$, $p < .01$, MSE = .035. Thus, analyses proceeded separately for each dependent measure. Within each dependent measure, repeated measures ANOVAs were used to assess main effects and interactions. All planned *t*-test comparisons used the Bonferroni correction to account for multiple comparisons. Below we present the data organized around the critical questions that motivated our study, as described in the Introduction.

Is there a multimedia advantage for learning procedures?

An ANOVA on free recall data revealed a main effect of presentation condition, $F(2, 100) = 74.138$, $p < .01$, MSE = .032. Planned comparisons using the Bonferroni correction demonstrated higher recall accuracy for multimedia ($M = .75$, SD = .21) relative to both picture-only ($M = .64$, SD = .20), $t(51) = 3.03$, $p < .01$ and text-only ($M = .33$, SD = .24) presentations, $t(51) = 10.59$, $p < .01$. In addition, picture-only presentations produced higher recall accuracy relative to text-only presentations, $t(51) = 9.59$, $p < .01$.

An ANOVA on order verification accuracy revealed a main effect of presentation condition, $F(2, 100) = 22.59$, $p < .01$, MSE = .008. Planned comparisons using the Bonferroni correction revealed higher accuracy following multimedia ($M = .86$, SD = .12) relative to text-only ($M = .74$, SD = .14), $t(51) = 5.50$, $p < .01$, but not picture-only ($M = .84$, SD = .12) presentations, $t(51) = .78$, $p > .05$. In addition, picture-only presentations resulted in higher order verification accuracy relative to text-only presentations, $t(51) = 5.71$, $p < .01$. Correct order verification response times mirrored the accuracy results, demonstrating a main effect of presentation condition, $F(2, 100) = 8.54$, $p < .01$, MSE = .713 (see Table 1). Planned comparisons revealed faster response times following multimedia relative to picture-only, $t(51) = 2.99$, $p < .01$ and to text-only presentations, $t(51) = 2.98$, $p < .01$. Picture-only response times, however, did not differ from text-only responses, $t(51) = .41$, $p > .05$. Overall, the results support multimedia as an effective format for conveying procedural sequences, with memory advantages (i.e. accuracy and speed) on both recall and order verification.

An ANOVA of format recall errors showed an effect of error type, $F(5, 250) = 43.75$, $p < .01$, MSE = .033 (see Table 1). Planned comparisons using the Bonferroni correction revealed that when participants made misattribution errors, they were more likely to misattribute multimedia presentations as picture-only, relative to any other error type (all p's $< .01$).

Does active integration and/or repetition play a role in the multimedia advantage?

In support of active integration, planned comparisons using the Bonferroni correction within the complementary multimedia group revealed higher free recall accuracy for

Table 1. Experiments 1 and 2 means and standard deviations for order verification (O.V.) task response time, as well as format recall error rates as a function of presentation type

| Task and condition | Experiment 1 | | | | Experiment 2 | | | |
| | Repetitious | | Complementary | | Repetitious | | Interleaved | |
	M	SD	*M*	SD	*M*	SD	*M*	SD
Order verification response time (seconds)								
Picture-only	6.23	1.77	6.24	2.16	6.81	2.40	6.90	1.82
Text-only	5.96	2.07	6.38	2.36	7.23	2.71	7.79	1.68
Multimedia	4.59	1.76	6.63	2.71	6.60	2.15	6.49	2.02
Format recall error rates (learned—misattributed)								
T-P	.012	.044	.033	.068	.075	.126	.100	.157
T-MM	.025	.076	.053	.172	.075	.114	.108	.124
P-T	.043	.087	.033	.068	.005	.095	.033	.068
P-MM	.056	.103	.093	.145	.108	.135	.083	.101
MM-T	.043	.099	.200	.231	.050	.095	.025	.061
MM-P	.370	.376	.547	.328	.300	.226	.292	.247

multimedia ($M = .67$, SD $= .23$) relative to text-only ($M = .34$, SD $= .18$), $t(24) = 6.091$, $p < .01$, but not picture-only, ($M = .64$, SD $= .16$) presentations, $t(24) = .484$, $p > .05$. The order verification task showed a similar pattern, but the complementary multimedia ($M = .81$, SD $= .13$) to text-only ($M = .76$, SD $= .12$) comparison did not reach significance, $t(24) = 1.93$, $p > .05$.

In support of repetition, significant presentation condition by multimedia format interactions demonstrated higher free recall (see Figure 2a) and order verification accuracy (see Figure 2b) following repetitious versus complementary multimedia, $F(2, 100) = 3.958$, $p < .05$, MSE $= .032$ and $F(2, 100) = 5.245$, $p < .01$, MSE $= .008$, respectively. Second, order verification response times mirrored these results, demonstrating a presentation condition by multimedia format interaction, $F(2, 100) = 20.937$, $p < .01$,
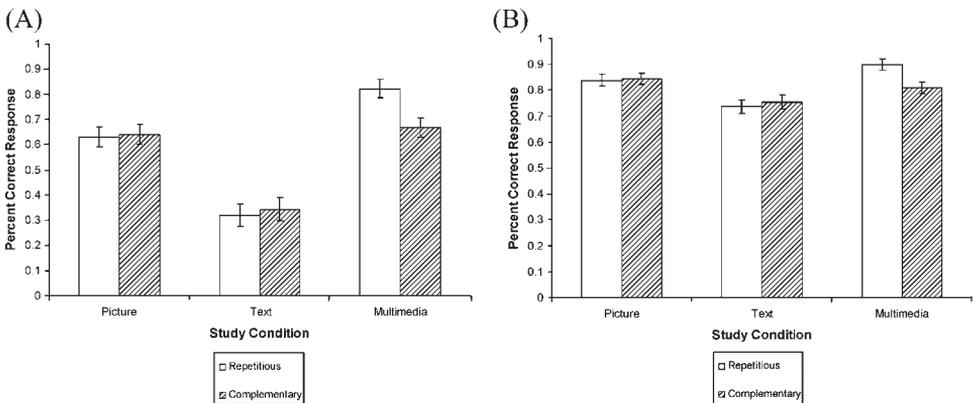

Figure 2. Experiment 1 mean repetitious and complementary group accuracy rates and standard error derived from the free recall (a) and order verification (b) tasks for picture, text and multimedia conditions

MSE = .713, with faster response times following repetitious ($M = 4.59$, SD = 1.26) relative to complementary ($M = 6.63$, SD = 1.62) multimedia.

As detailed in Table 1, source-monitoring accuracy was particularly low following both multimedia types, as participants tended to misattribute these experiences as picture-only. We note that the complementary multimedia group also frequently misattributed multimedia as text-only relative to the repetitious multimedia group, $t(50) = 3.226, p < .01$, thus increasing the overall misattribution rate.

Are object assembly tasks well-served by multimedia learning?

An ANOVA on assembly accuracy revealed a main effect of presentation condition, $F(2, 100) = 17.174, p < .01$, MSE = .085. Planned comparisons using the Bonferroni correction showed greater accuracy following multimedia ($M = .88$, SD = .26) relative to text-only ($M = .61$, SD = .39), $t(51) = 4.09, p < .01$, but not picture-only presentations, $t(51) = .817$, $p > .05$ and following picture-only ($M = .91$, SD = .19) relative to text-only presentations, $t(51) = 5.12, p < .01$. Assembly times also showed a similar pattern, $F(2, 100) = 27.279$, $p < .01$, MSE = .109. Planned comparisons revealed faster assembly times following multimedia ($M = 31.17$, SD = 11.33) relative to text-only ($M = 44.07$, SD = 15.14), $t(51) = 6.66$, $p < .01$, but not picture-only ($M = 30.76$, SD = 12.75) presentations, $t(51) = .207, p > .05$.

What are the roles of active integration and repetition in learning for object assembly?

In support of active integration, complementary multimedia ($M = .81$, SD = .33) produced higher assembly accuracy relative to text-only ($M = .60$, SD = .43), $t(51) = 2.24, p < .025$, but not relative to picture-only ($M = .90$, SD = .20) presentations, $t(24) = 1.36, p > .05$,. In support of repetition, assembly time produced a presentation condition by multimedia format interaction, $F(2, 100) = 4.853, p < .01$, MSE = .109, with faster assembly times following repetitious relative to complementary multimedia.

DISCUSSION

To summarize these results, multimedia appears to produce memory advantages on tasks requiring both verbal (recall, order verification) and temporal (order verification) knowledge, and this advantage appears to be a result of both repetition and active integration. Data from free recall and order verification suggest that the relatively limited depictions available in complementary multimedia produce active integration advantages, relative to the text-only condition. That is, even a very limited depiction (e.g. skis) that accompanies text can improve memory relative to text alone. Further, results suggest that the inherent repetition in repetitious multimedia can lead to memory advantages relative to the active integration effects alone as seen with complementary multimedia. In contrast, repetition in single-format presentations does not benefit memory performance.

However, the advantage may be task dependent, and limited to memory-based activities, as object assembly following multimedia was no better than following pictures alone. Adding pictures to text facilitates assembly, but more generally pictures (whether alone or with text) appear to provide the necessary information for quick and accurate toy assembly.

Thus, the object assembly results suggest a role for both active integration (in the case of assembly accuracy) and repetition (in the case of assembly time) in a multimedia advantage. It must be noted, however, that object assembly performance based on pictures alone or multimedia were roughly equivalent. Thus, repetition and active integration may not be as important for object assembly as they are for memory. Between pictures and text, pictures more directly embody the spatial relationships needed for accurate construction. This aligns with memory benefits that traditionally accrue as a function of transfer appropriate processing (e.g. Morris, Bransford, & Franks, 1977); pictures, as compared to text stimuli, may afford a more appropriate stimuli source for later dealing with actual objects. In this case, the additional perceptual information derived from pictures relative to texts appears to be useful towards actual object assembly (Schnotz, 2001)—this is in contrast to the conceptual information necessary for completing free recall and order verification. Thus, when text is used to convey information to be later applied to object assembly, instructional system developers should be particularly concerned about informational (or as in this case, gist) equivalence across multimedia formats. When considering the spatial information necessary for assembly, this finding may not be entirely surprising, but is often nonetheless ignored or discounted.

Finally, despite the memory advantage for multimedia, participants seemed largely unaware of a combined text-picture benefit. This is shown by participants' high misattribution rates for identifying multimedia as picture-only, and also specifically as text-only with complementary multimedia.

EXPERIMENT 2

Experiment 1 provided evidence that active integration influences multimedia advantages. To test the limits of such benefits, we examined the degree to which the amount of active integration might influence potential learning benefits. A multimedia format that presents pictures and text in an interleaved (as opposed to simultaneous) manner demands active mental processing (and integration) of text and pictures *across* the entire assembly sequence. In other words, interleaved presentations necessitate maintaining a mental representation of each step, as well as integrating formats across each step of an unfolding sequence; in contrast, non-interleaved (repetitious) presentations require no translation across steps, limiting integration to within-step activity. Mayer's (1997) *dual coding* principle suggests that active mental integration of multimedia components across steps should impart memory advantages. Because interleaved multimedia necessitates further integration activities, we predicted that interleaved presentations should lead to better memory compared to traditional, repetitious multimedia.

An alternative hypothesis is offered by Sweller's (1988, 1999) cognitive load theory, which suggests that integrative processes can produce undue working memory load. In this case, attempts to integrate presentation materials both across and within steps may cause difficulty for participants given limited working memory resources. This leads to a competing hypothesis that interleaved multimedia should lead to equal or worse memory as compared to repetitious multimedia. This distinction is similar to one by made by Mayer (1997) regarding the relative effectiveness of multimedia with temporally and spatially contiguous, as opposed to non-contiguous components. According to this view, difficulty mentally integrating pictures and text (e.g. when information is not temporally or spatially contiguous) may create high cognitive load and hurt comprehension.

METHOD

Participants and design

Forty-one Tufts University undergraduates participated for partial course credit. Twenty participants viewed interleaved multimedia presentations and 21 viewed repetitious multimedia presentations. Each participant group additionally viewed assembly sequences in picture- and text-only comparison conditions that did or did not control for repetition effects, respectively. We therefore incorporated a mixed design with multimedia type as a between-participants factor (2 levels: interleaved, repetitious), and presentation format as a within-participants factor (3 levels: multimedia, picture-only, text-only).

Materials and apparatus

All materials were identical to those in Experiment 1, with the exception of interleaved multimedia replacing complementary stimuli. Interleaved sequences were created by combining pictures and text in a single assembly sequence, but only across steps (rather than within steps) of the sequence. For example, Figure 3 demonstrates an interleaved sequence with steps 1 and 3 in picture format, and steps 2 and 4 in text format. Step 5, the completed object, always combined picture and text. Two interleaved versions of each sequence were created, one as shown in Figure 3 with picture first, and another with text first. The two interleaved sequence types were counterbalanced across sequences and participants. As in Experiment 1, single format comparison conditions (i.e. picture- and text-only) corresponded with the multimedia groups to control for repetition effects. In the interleaved multimedia group, single-format sequences presented each step *once*. In the repetitious multimedia group, single format sequences presented each step *twice* (i.e. picture above picture, or text above text).

Procedure

The procedure was identical to that in Experiment 1, with participants learning a total of 21 sequences, 18 to be applied to the memory tasks, followed by 3 additional to be applied to object assembly. As in Experiment 1, the format within which each sequence appeared and the order of sequence presentation were counterbalanced between and randomized within participants, respectively.

RESULTS

To confirm the utility of separate analyses by our four dependent tasks, a single 2(multimedia type: interleaved, repetitious) × 3(presentation format: pictures, text, multimedia) × 4(dependent task: free recall, order verification, format recall, object assembly) omnibus ANOVA was conducted; results confirmed a significant presentation

Figure 3. A sample procedural sequence depicted in the interleaved multimedia format

format by dependent task interaction, $F(6, 234) = 18.413$, $p < .01$, MSE $= .034$ and a significant three-way interaction, $F(6, 234) = 2.867$, $p < .05$, MSE $= .034$. Thus, analyses proceeded separately for the dependent measures.

Interleaved versus repetitious multimedia?

Two ANOVAs revealed main effects of presentation format on both free recall, $F(2, 78) = 59.869$, $p < .01$, MSE $= .035$ and order verification, $F(2, 78) = 14.315$, $p < .01$, MSE $= .008$ (see Figure 4), replicating overall higher performance following multimedia relative to pictures and text. These two tasks, however, revealed no main effect of multimedia type (both F's < 1; see Table 1). An ANOVA of source monitoring data also failed to reveal a main effect of multimedia type ($F < 1$; see Table 1); that is, there were similar error rates for interleaved and repetitious multimedia.

Are object assembly tasks better served by interleaved or repetitious multimedia?

An ANOVA on assembly accuracy data revealed a main effect of presentation format, $F(2, 78) = 15.439$, $p < .01$, MSE $= .11$, but no presentation format by multimedia type interaction, $F(2, 78) = 15.439$, $p > .05$. Planned comparisons using the Bonferroni correction revealed higher assembly accuracy following repetitious ($M = .93$, SD $= .18$) relative to interleaved ($M = .76$, SD $= .30$) multimedia, but only with marginal significance (at $\alpha = .025$), $t(39) = 2.62$, $p < .05$. Further, assembly accuracy following interleaved multimedia exceeded that of text-only ($M = .58$, SD $= .39$), $t(22) = 3.51$, $p < .01$, but not picture-only ($M = .92$, SD $= .17$) presentations, $t(22) = .153$, $p < .05$. Assembly time did not reveal any effects of presentation format or multimedia type (all p's $> .05$).

DISCUSSION

For memory tasks, interleaved multimedia appears to be as effective as repetitious multimedia in conveying procedural sequences. This finding suggests that the multimedia
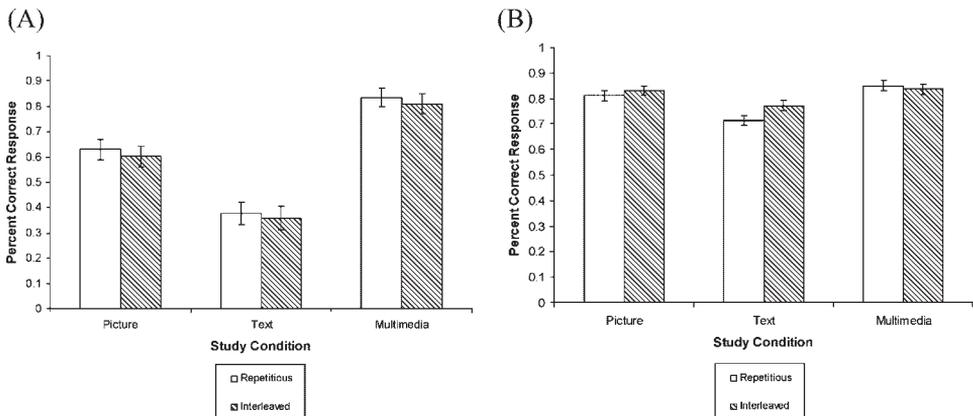

Figure 4. Experiment 2 mean repetitious and interleaved group accuracy rates and standard error derived from the free recall (a) and order verification (b) tasks for picture, text and multimedia conditions

advantage for procedural information does not require simultaneous presentation of pictures and text. Rather, participants seem able to maintain sequence steps within working memory and then integrate the two formats across steps. This effect may be specific to procedures rather than general to all multimedia, however. Procedures necessitate maintaining and updating sequential steps over the course of an assembly sequence. The high level of active integration demanded by interleaved multimedia did not produce memory advantages relative to the repetition and integration involved with repetitious multimedia. Thus, the greater integration necessitated by interleaved presentations did not lead to increased benefits, nor did it lead to performance decrements, on memory tasks. We do note that across our two experiments, interleaved multimedia produced numerically higher memory performance relative to Experiment 1's complementary multimedia. This suggests greater memory advantages from integration across rather than within steps, in addition to repetition benefits; this is speculative, however, and our design precludes formal analysis.

For object assembly, interleaved multimedia appeared to facilitate performance relative to single formats. However, while interleaved multimedia can support object assembly as well as picture-only presentations, it cannot match performance following repetitious multimedia.

Overall, repetitious multimedia facilitates object assembly relative to interleaved multimedia presentations, but the two multimedia types did not differ in their support of memory performance. This finding is consistent with our earlier discussion of the role of spatial information in assembly instructions, as well as with the results of Experiment 1. With interleaved multimedia, pictures are only available on every other step, thus requiring spatial information to be held in working memory. Interestingly, participants misattributed interleaved multimedia as picture-only to the same extent as repetitious multimedia. This suggests a misattribution of multimedia experiences to pictures, although the overall multimedia advantage indicates that participants are, at some level, also using the text.

GENERAL DISCUSSION

Theoretical implications

By manipulating multimedia formats we gained insight into mechanisms underlying the multimedia advantage, as it applies to learning procedures. Research suggests that multimedia advantages accrue partially as a result of active integration afforded by dual coding within working memory (Mayer, 1997). This view was supported by Experiment 1, demonstrating memory advantages following complementary multimedia relative to text alone. Specifically, even the sparse image available in a single complementary multimedia step can demand dual coding, encourage active integration of the two formats, and impart memory advantages relative to text alone, without any obvious detrimental learning effects due to cognitive load. However, we also demonstrated that repetition contributes to the multimedia advantage, as repetitious multimedia outperformed complementary multimedia on a variety of measures. This finding is in contrast to Sweller's (1988, 1999) notion that repetition may hinder rather than facilitate learning; it is our belief that while repetition within formats may not be beneficial (judging by the similar means in groups with repeated relative to non-repeated single-format presentations), repetition across formats may prove beneficial towards memory performance, extending both classic and contemporary work

on repetition effects. Of course, success in the application of new knowledge varies importantly by task demands; with object assembly, repetition across formats does not benefit performance. Further, repetition may only be beneficial in the present case due to many participants being unfamiliar with Kinder Egg[TM] assembly tasks, in line with Sweller's redundancy principle (i.e. repetition aiding novices and not experts; Sweller, Chandler, Tierney, & Cooper, 1990); future work should assess the relative effectiveness of active integration and repetition in both novices and experts. Note that while we have no direct measure of whether participants were in fact studying *both* the pictures and text during repetitious multimedia, memory results repeatedly demonstrate the advantage of adding texts to pictures. That is, repetitious multimedia leads to memory advantages relative to pictures alone (see also Brunyé et al., 2006). If participants were not reading the texts, we would not see this advantage. Thus, active integration and repetition appear to maximize the multimedia advantage, in line with classic investigations of learning (Guthrie, 1935; Levie & Lentz, 1982).

Additionally, for procedures which require successful integration of sequential information, active integration of formats within steps may not be critical, as seen in the Experiment 2 comparison of interleaved and repetitious multimedia. That is, active integration benefits appear to accrue across steps, in addition to within steps. There are at least two mechanisms by which participants may integrate pictures and text in interleaved multimedia. The first is by maintaining image- or text-based representations within working memory, into which the alternate format can be actively integrated. This results in a final memory representation that is applied to memory tasks similarly to repetitious multimedia. This interpretation aligns with Mayer's (1997, 2001) notion of active integration across multimedia formats, but extends it to procedural sequence learning by demonstrating the relative effectiveness of active integration across, in addition to within, steps. The second mechanism is by extracting the steps from the final (step 5) image of interleaved multimedia. This latter possibility is supported by work showing that final state diagrams can facilitate learning of procedures, particularly when the constituent steps can be derived with relative ease (Novick & Morse, 2000). This latter interpretation suggests that the final state diagram may serve as a consolidation tool. Future work should attempt to disentangle the relative influences of final state diagrams and the active integrative process, particularly with regard to potentially interactive effects of cognitive load.

Regardless of interpretation, our results suggest that at least with procedural sequences, the two formats need not be presented simultaneously, but rather can be integrated from interleaved picture and text presentations. These data have important implications for existing views of multimedia benefits (e.g. Mayer, 1997), particularly as applied to learning procedures (as compared to the traditionally studied domain of expository learning). It also appears that there is an important distinction between representations that can be readily applied to conventional memory tasks versus object assembly. That is, to the extent that there is significant overlap between the learning and testing circumstances (e.g. symbolic and/or perceptual equivalence), performance should improve. Thus, while there appears to be no distinction between repetitious and interleaved multimedia as applied to our memory tasks, the distinction becomes readily apparent with actual object assembly. This result underscores the importance of investigating not just what individuals remember but also their ability to use what they remember to perform actual tasks. Of course, for most procedures learners generally expect to both understand and perform the relevant tasks. Nevertheless, future research should examine the cognitive mechanisms that may be uniquely responsible for multimedia advantages in learning procedures, particularly as

they serve applied (as opposed to memory) tasks. Our studies here present a step in this direction.

Practical implications

The present research has several implications for educational and applied practice. First, these results demonstrate that multimedia facilitates memory for procedural sequences, as well as performance on assembly tasks that rely on such memory. These findings complement existing research demonstrating the effectiveness of the multimedia format in conveying both procedural (Brunyé et al., 2006; Diehl & Mills, 1995; Glenberg & Langston, 1992; Marcus et al., 1996; Stone & Glock, 1981; Zacks & Tversky, 2003; but see Novick & Morse, 2000) and declarative information (e.g. Levie & Lentz, 1982; Mayer, 1989; Mayer, 1997; Mayer, 2001; Mayer, Steinhoff, et al., 1995; Mayer & Gallini, 1990; Peeck, 1994; Sweller, 1999). Thus, whether individuals must simply remember the information (as is true for pencil-and-paper exams), or successfully apply that knowledge to some activity (as is true for bicycle assembly), multimedia appears to be a beneficial learning format.

Second, how one uses the information is necessarily a function of how that information was learned. Our results suggest that pictures may be as useful as multimedia for applied tasks such as assembly wherein the spatial information is relatively important and is directly depicted. This is akin to transfer-appropriate processes, for which the likelihood of retrieval from memory is directly associated with the encoding or learning conditions (i.e. Blaxton, 1989; Morris et al., 1977). Thus, while memory tasks are better-served by multimedia relative to picture-only presentations, tasks that require direct manipulation of the presented objects may be best supported by pictures, although not hindered by the addition of text to pictures. This is likely contingent upon whether parts are easily identifiable, as one can imagine the utility of labeling parts for bicycle assembly where some parts may not be easily distinguishable from one another. This also means we might envision tasks for which spatial relationships between objects might not be important, and thus multimedia presentations of such material might not result in performance benefits (e.g. understanding abstract steps in computing a mathematical formula). Of course, Kinder Egg^{TM} toys in particular may be rather amenable to picture-only presentations, may represent a relatively simple assembly genre, and may not generalize well to all assembly tasks. More complex assembly tasks might demand more or less spatial and verbal detail; future work should examine the potential interactions between task complexity and supporting presentation formats.

Finally, while multimedia appears to be advantageous for presenting procedures, individuals do not seem entirely aware of the benefits. In these experiments, as well as others (Brunyé et al., 2006), participants who learned with multimedia tended to misattribute their learning as picture-only. It appears that during multimedia learning there is either a picture-focus effect or little phenomenological impact of the text. Judging by the clear multimedia advantages relative to picture-only learning, the latter may be at play. Thus, while the text within a multimedia presentation influences comprehension, participants tend to recall the pictures more so than the text. In a practical sense, it is important not to undervalue the utility of text, even if it appears to be underestimated and undervalued by learners during think-aloud procedures or value assessments. Indeed, pictures may generally be seductive to the extent that they provide a concise format from which to gather information (e.g. Garner, Gillingham, & White, 1989; Harp &

Mayer, 1998). This may be of limited importance when the pictures and text are repetitious, but in the case of complementary multimedia such an effect may limit the learning of important information found within the text. In a theoretical sense, the bias towards remembering multimedia presentations as picture-only might provide insights into the form of mental representations resulting from multimedia learning; that is, at least at a phenomenological level, these memory representations may be relatively imagery-based.

These three implications are critically important given current intuitions about and adoption of multimedia in many educational settings. Given the growing evidence that multimedia can facilitate learning, it is important to determine the conditions under which those benefits are more or less likely to occur. To some degree, this work becomes translational in that it takes descriptions of what multimedia is and explanations of how it works, and attempts to suggest effective learning conditions as a function of those descriptions and explanations. Future work in our laboratories will investigate the connections between these results and actual classroom activities, in the hopes of deriving specific applications for multimedia-based educational experiences.

Limitations

A potential limitation to the present design is the inherent difficulty in creating truly repetitious multimedia across picture and text formats; however, our present measures do not necessitate memory beyond the gist information (e.g. attach the skis to the feet; attach the propeller to the plane) clearly provided by both pictures and texts. Results from our order verification task demonstrate that participants were able to extract gist information from both formats. Specifically, there was no evidence for transfer-appropriate mechanisms contributing to order verification task performance: following picture- and text-only learning, accuracy and response time for within format (picture and text, respectively) and across format (text and picture, respectively) learning and testing trials were quite similar. If the picture and text versions of a single sequence largely differed in gist content, one might expect higher performance within- (e.g. picture testing trials following picture-only learning) relative to between-format (e.g. picture testing trials following text-only learning) combinations. Thus, it appears that our method for generating text versions of picture sequence steps resulted in memories that were well-applied across testing formats, suggesting a high degree of gist equivalence between our picture and text sequence versions.

Related to the above limitation, the Experiment 1 design (repetitious group) controlled for repetition effects in the single-format conditions (text- or picture-only) by presenting sequence steps twice simultaneously. Of course, over time participants were likely to notice that there was no need to read the second body of text, or study the second image, as it was merely a repetition of what was displayed immediately above; as a result, participants may have ignored the repeated texts or images in the single-format comparison conditions. In fact, Experiment 1 results suggest that participants did not attend to the repetitious single-format content; specifically, the repetitious and complementary groups produced similar performance following both picture- and text-only learning. This is an interesting finding in that the repetitious group always contained repeated single format sequences (each step appeared twice simultaneously on the screen), while the complementary group always contained non-repetitious single format sequences (each step appeared once on the screen); however, the single-format repetition did not appear to produce memory benefits. Thus, while we cannot guarantee whether participants studied or

disregarded repeated information sources in the single-format conditions of Experiment 1, these results further emphasize the mnemonic benefits of repetition in dual-format, but not single-format, presentations.

Final comments

In summary, multimedia effectively presents procedural information, particularly when that multimedia is repetitious. This effect is likely for a variety of reasons. First, there appear to be additive effects of active integration and repetition. Second, the transfer of knowledge to object assembly is facilitated when substantial overlap exists between the perceptual components of study and test materials. Third, active integration facilitates learning when it is across, as well as within procedural steps. In a theoretical sense our results contribute to the understanding of memory mechanisms underlying multimedia advantages. In a practical sense, our results inform the design of learning interfaces that can potentially reduce confusion often encountered by the bicycle assembler, the student studying from a textbook, and the child putting together a toy puzzle.

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