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Working Memory Capacity and Mobile Multimedia Learning Environments: Individual Differences in Learning While Mobile

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The present study examined the effects of individual differences in working memory capacity (WMC) on learning from a historical inquiry multimedia tutorial in stationary versus mobile learning environments using a portable digital media player (e.g., iPod). Students with low (n = 44) and high (n = 40) working memory capacity, as measured by the OSPAN memory span test, were randomly assigned to either a stationary (n = 54) or mobile (n = 30) instructional environment. In the stationary environment, participants viewed the tutorial while sitting in a chair at a desk in a computer lab. In the mobile environment, participants walked down a hallway following a course indicated by signs on the floor. This walking and navigating, while engaging in the multimedia tutorial, represents a divided attention task similar to the type of environment one might encounter in the real world. Overall, students with high WMC outperformed students with low WMC on measures of recall and transfer of the historical inquiry strategy. In addition, students in a stationary instructional environment outperformed students in a mobile instructional environment. Finally, interaction effects indicated that low WMC students in a mobile instructional environment performed the most poorly.

Mobile learning, or mLearning, is typically defined as learning with mobile technologies (see Laouris & Eteokleous, 2005). These types of definitions generally emphasize the ability to move beyond place-bound teaching and learning environments (Goh & Kinshuk, 2006; Seppala & Alamaki, 2003) based on the application of wireless educational technologies (e.g., mobile phones, personal digital assistants, laptop computers, portable digital media players). Educational research into the efficacy of mobile learning and mobile technologies tends to focus on "their use embedded in classroom practice, or as part of a learning experience outside the classroom" (Naismith, Lonsdale, Vavoula, & Sharples, 2006, p. 11). One arena in which this is especially the case is the use of portable digital media players (e.g., iPods, Zunes). In recent years, educators across the globe have begun to employ portable digital media players, especially iPods, as educational platforms (see Belanger, 2005; Cebeci & Tekdal, 2006; Trelease, 2006). There is, however, a paucity of research addressing the potential individual differences that may be apparent in the educational use of multimedia instruction on portable digital media players.

In response, the present research was designed to examine the individual efficacy of portable digital media players as multimedia instructional environments. Recent research into multimedia instructional environments has demonstrated the general effectiveness of multimedia learning (see Mayer 2001, 2005) and the development of specific principles that facilitate or inhibit learning in multimedia instructional environments (Ginns, 2005; Kalyuga, Chandler, & Sweller, 1999). One facet of multimedia learning that has suffered from neglect, however, is the role of individual differences. Previous research has identified two main individual difference variable of interest, relative to multimedia learning: spatial ability (Moreno & Mayer, 1999) and prior knowledge (Ollerenshaw, Aidman, & Kidd, 1997). Sanchez and Wiley (2006), however, investigated the individual difference effects of working memory capacity (WMC), a measure of attentional control, on learning within an illustrated, web-based expository-text learning task completed on a stationary desktop computer. Sanchez and Wiley found that students with low working memory capacity (poor atttentional control) had poorer cognitive performance than students with high working memory capacity after viewing the illustrated expository text tutorial with seductive details (i.e., attention diverting extraneous, non-relevant words and pictures). That is, individual differences in attentional control, as measured by working memory capacity, had a significant impact on student learning in a multimedia instructional environment. Thus, the present study was designed to examine the effects of individual differences in WMC on learning in stationary versus mobile learning environments using portable digital media players.

Mobile Learning Environments

Mobile learning, in general, refers to the use of mobile technologies to allow students flexibility in where and when to learn. Typical mobile technologies include wireless laptops, PDAs, tabletPCs, and mobile phones (Fallahkhair, Pemberton, & Griffiths, 2007), although portable digital media players are also being used for mobile learning (see Chan, Lee, & McLoughlin, 2006; Trelease, 2006). These mobile technologies are currently being used to foster learning in classrooms, laboratories, field trips, distance education environments, and informal learning environments (Goh & Kinshuk, 2006), as well as across domains such as language learning (Chinnery, 2006), teacher education (Seppala & Alamaki, 2003), anatomy (Trelease, 2006), and problem-based learning (Massey, Ramesh, & Khatri, 2006). It should be noted, however, that mobile learning is still in its infancy, that mobile learning's very definition is still in question (see Laouris & Eteokleous, 2005), and that most mobile learning endeavors are "not always stable, mature or well understood" (Traxler & Kukulska-Hulme, 2005, p. 5).

Mobile learning research tends to focus on three areas, new technology development, new technology evaluation and existing technology application. Mobile learning technology development research is typified by a special issue of the International Review of Research in Open and Distance Learning (Ally, 2007). This special issue contains articles addressing (a) mobile technology usability (Kukulska-Hulme, 2007), (b) use of PDAs for distance learning (Rekkedal & Dye, 2007), (c) the growth of mobile hardware and networking technology (Caudill, 2007), and (d) the development of an advanced instant messaging system (Kadirire, 2007). In each case, the articles were focused on the development of new technology, but did not empirically evaluate the applicability of the technology developed. Research that focuses on the evaluation of the viability of technology developments is typified by a special issue of the Journal of Computer Assisted Learning (Sharples, 2007). This special issue contains articles that address (a) the effects of large shared video-display groupware on the collaboration of students working with PDAs or tabletPCs (Liu & Kao, 2007); (b) the effects of a cross-platform language learning service, provided through interactive television and mobile phones, on language learning (Fallahkhair, Pemberton, & Griffiths, 2007); and (c) the effects of a PDA-based field-trip experiential learning guide on knowledge construction (Lai, Yang, Chen, Ho, & Chan, 2007). In each of these articles, new technology developments were employed with real users and the efficacy of the new technologies evaluated.

Finally, mobile learning technology application research focuses on the use of existing technologies in current classroom settings. Examples of this type of research include (a) sending short vocabulary lessons via SMS text messaging to students in an EFL class in Japan, resulting in increased vocabulary development (Thornton & Houser, 2004); (b) exchanging SMS text messages and mobile phone-based digital pictures between student teachers and teacher supervisors, resulting in greater use of casual time (e.g., riding on a bus) for educational purposes (Seppala & Alamaki, 2003); (c) using PDAs to access Internet-based medical services in medical education, resulting in immediate access to necessary information (Smordal & Gregory, 2003); and (d) using PDAs to write reflections, send emails, and pictorially document events by student teachers and teacher supervisors of pre-service science educators, resulting in increased student teacher organization (Pedersen & Marek, 2007). In each of these articles, established technologies were applied to current educational settings without the need for the development of new interfaces, knowledge bases, or technological enhancements.

What is not present in this research addressing mobile learning technology development, evaluation, and application is the examination of individual differences, or learner characteristics, and how these individual differences affect learning and behavior. How might individual differences in dexterity, vision, hearing, memory or attention affect learning and performance using mobile learning technologies?

Working Memory Capacity and Individual Differences

Working memory capacity (WMC) represents the ability of an individual to maintain focus on a primary task while also maintaining relevant information in working memory and retrieving relevant information from long-term memory, especially in the presence of distraction (Feldman, Tugade, & Engle, 2004; Unsworth & Engle, 2007). That is, WMC moves beyond a basic measure of working memory storage capacity (see Miller, 1956) to include both storage *and* processing capacity (see Daneman & Carpenter, 1980; Kane & Engle, 2003). Thus, ultimately, WMC is a measure of control; that is, the ability to control the maintenance of information in working memory (storage) and the retrieval from long-term memory of information relevant to a current problem or situation (processing). This control is most evident when there are internal (e.g., thoughts, drives, feelings) or external (e.g., talking, music, motion) distractions taxing the attentional system (Unsworth & Engle, 2007).

There is an extensive body of literature indicating that an individual's ability to demonstrate this type of attentional control positively affects performance on complex mental tasks, including general fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002), long-term memory activation (Cantor & Engle, 1993), attentional control (Kane, Bleckley, Conway, & Engle, 2001), resistance to proactive interference (Lustig, May, & Hasher, 2001), primary memory maintenance and secondary memory search (Unsworth & Engle, 2007), and resistance to goal neglect (Kane & Engle, 2003). These positive effects resulting from greater WMC have led to several studies examining the effects of individual differences in WMC on various types of complex cognitive tasks. These studies have indicated that that those with higher WMC perform better than those with lower WMC in the areas of reading comprehension (Daneman & Carpenter, 1980), language comprehension (Just & Carpenter, 1992), vocabulary learning (Daneman & Green, 1986), reasoning (Conway et al., 2002; cf. Buehner, Krumm, & Pick, 2005), computer language learning (Shute, 1991), lecture note taking (Kiewra & Benton, 1988), Scholastic Aptitude Test performance (Turner & Engle, 1989), mnemonic strategy effectiveness (Gaultney, Kipp, & Kirk, 2005), and storytelling (Pratt, Boyes, Robins, & Manchester, 1989). This research has demonstrated a strong, positive relationship between variations in WMC and variations in complex cognitive task performance.

One domain of complex cognitive tasks that has seen little research related to WMC is multimedia learning. The examination of individual differences in WMC on multimedia learning is of interest as both WMC and multimedia learning are influenced by attentional control (see Mayer, 2001, 2005). Specifically, multimedia learning suffers when students' attention is split between two or more multimedia elements, such as animation with concurrent on-screen text captioning (Kalyuga, Chandler, & Sweller, 1999; Mayer & Moreno, 1998) or when seductive details – extraneous words, pictures, sounds or music – are added to a multimedia tutorial (Harp & Mayer, 1998; Mayer & Jackson, 2005). In contrast, Harp and Mayer (1998) and Mautone and Mayer (2001) found that learning was facilitated by the presence of cues that guided the learners' attention and highlighted the structure of the information provided.

What is the Relationship between Mobile Learning and Working Memory Capacity?

According to Vavoula and Sharples (2002), the term *mobile*, within mobile learning, indicates that learning may take place in multiple locations, across multiple times, and addressing multiple content areas. Each of these aspects of mobile, however, is embedded in the technology itself, not the learner. Indeed, Vavoula and Sharples specify that the mobile technological system that supports this multi-location, multi-time and multi-content learning must be portable, accessible and flexible, respectively. One aspect that is missing from this description is that of a mobile learner. That is, what attributes of the individual are important in a mobile learning situation? Furthermore, is there a difference in learning when an individual is physically moving, learning while mobile (e.g., walking while engaging in a lesson on an iPod), or stationary (e.g., sitting on a park bench engaging in a lesson on an iPod) while utilizing mobile learning technologies?

The purposes of this study were to (a) evaluate the effects of multimedia learning in stationary versus mobile learning environments using portable digital media players; (b) evaluate the existence of a general working memory capacity effect within multimedia instruction; and (c) evaluate whether working memory capacity differentially affected multimedia learning in stationary and mobile learning environments using portable digital media players.

METHODS

Participants and Design

Participants in this study were 84 undergraduate students (58 males, 26 females), with a mean age of 19.7 years. Participants were enrolled in a core-curriculum health education course at a large research university in the southeast and received course credit for participation. The 84 participants were derived from a larger sample of 147 students who were administered the OSPAN working memory span text. Of the 147 students, only those participants that scored in the upper ($n = 40$) or lower ($n = 44$) quartiles were included as participants. Participants were then randomly assigned to either the stationary ($n = 54$) or mobile ($n = 30$) learning environment group. The design of the present experiment was a 2 X 2 factorial design with working memory capacity (low WMC, high WMC) and learning environment (stationary, mobile) as between-subject variables.

Materials and Apparatus

Working memory capacity and the OSPAN task. WMC was measured using the OSPAN operation-span task (La Point & Engle, 1990; Turner &

Engle, 1989). To complete the OSPAN task participants maintained a list of unrelated words in memory while solving a series of basic math problems. Specifically, participants were shown a series of math-word sentences in the form of "IS (2 + 6) - 2 = 4 ? Car" or "IS (9 – 5) / 2 = 3 ? House." Participants read each math statement aloud and answered "yes" or "no" aloud as to the correctness of the math statement, followed by reading the unrelated word aloud. Participants viewed and read aloud one math-word sentence at a time on a computer screen and, without pausing, clicked a "Continue" button to advance to the next math-word sentence. Participants responded to a set of 2 to 6 math-word sentences before being asked to recall the unrelated words from that set, in order, and typing the words into a text box on the computer screen. The OSPAN score was determined by counting the number of words recalled for those sets in which the participant recalled all words, in order, correctly; thus, if a participant recalled *all* four words from a four math-word sentence set, in proper order, the participant would receive four points. Participants viewed 15 sets of math-word sentences, 3 sets each containing 2 to 6 math-word sentences, for a total of 60 math-word sentences and a maximum potential score of 60. The order of the math-word sets and the math-word sentences within each set were randomized for each participant. The mean OPSAN scores for the high WMC and low WMC groups were 28.79 (SD = 5.42) and 5.63 (SD = 2.87), respectively.

SCIM historical inquiry multimedia tutorial. The SCIM (summarizing, contextualizing, inferring, monitoring) historical inquiry multimedia tutorial was (a) 3.5 minutes in length, (b) based on 16 images with concurrent narration, (c) created using Adobe's Flash™, and (d) focused on both historical inquiry, generally, and the SCIM strategy for historical inquiry, specifically (see Figure 1). The first section of the tutorial discussed the general historical inquiry cycle including the asking of *historical questions*, the gathering of *historical sources*, the analyzing of historical sources to yield *historical evidence*, and the creating of *historical interpretations* based on the resultant historical evidence that addresses the original historical questions. The second section of the tutorial described the SCIM strategy for historical inquiry. The SCIM strategy consists of analyzing a specific source, such as a letter, by first *summarizing* the apparent and observable evidence, then *contextualizing* the source within the time and place in which the source was created, then *inferring* from the source conclusions that lie beyond the source, and finally, *monitoring* one's own thoughts for outstanding questions, needs for additional information beyond the source, and the relevance of the source to the guiding historical questions

Stationary and mobile learning environments. Participants viewed the historical inquiry multimedia tutorial on 5th generation iPods (i.e., video iPods) with 2.5” view screens and Altec Lansing™ headphones in one of two conditions, stationary or mobile. In the stationary condition, participants viewed the tutorial while sitting in a chair at a desk in a computer lab. In the mobile condition, participants were first provided with a random number from 1 to 3 and then asked to walk 25 yards down a hallway, and back, repeatedly, until the tutorial came to an end. Every 5 yards along this walk was a two-sided sign on the floor that included the numbers 1, 2 and 3, and above each number an arrow pointing left or right (see Figure 2). Participants were instructed to walk to the side of the sign indicated by the arrow above the number to which they were assigned. This walking and navigating while learning within a mobile learning environment represents a divided attention task similar to the type of environment one might encounter in the real world.

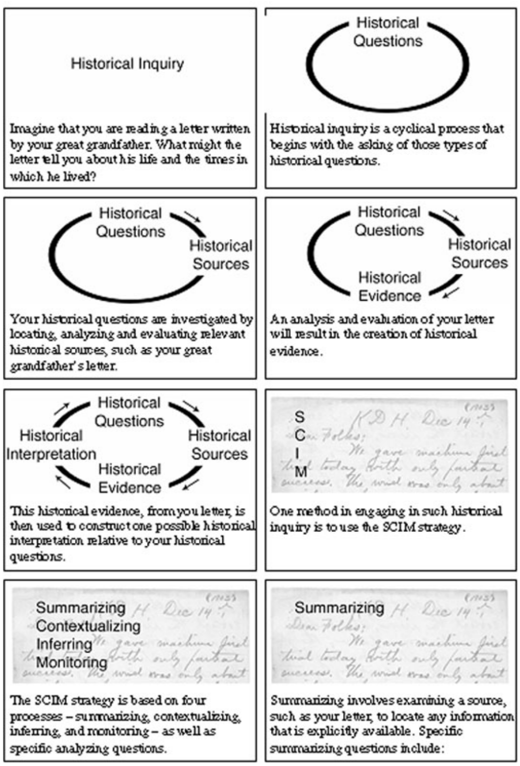
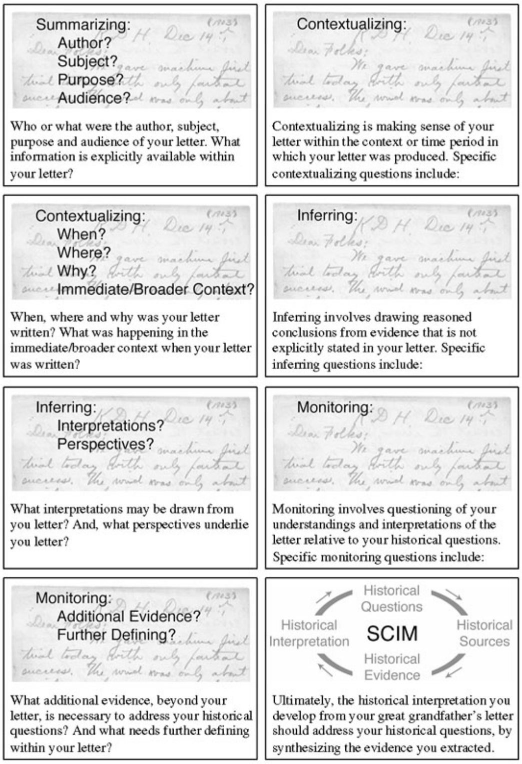


Figure 1. Frames of the SCIM historical inquiry multimedia tutorial with concurrent narration.



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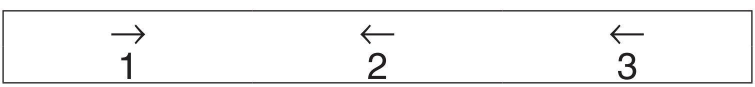

Figure 2. Directional signs used in the mobile learning environment.

Recall and transfer tests. Participants' recall of the SCIM historical inquiry process was assessed using a single open-ended question: "Please provide an explanation of historical inquiry and the SCIM strategy." Two trained scorers evaluated each response (r = .92) such that a response received one point for addressing each of the four stages of the general historical inquiry cycle and two points for defining each of the four SCIM phases. Thus, the maximum score for the recall test was 12. Participants' ability to transfer SCIM historical inquiry knowledge was assessed using four short-answer questions: (1) What could you do to increase the validity or accuracy of your historical interpretation?; (2) From a historical inquiry perspective, why is understanding the past so difficult?; (3) How might you go about analyzing a picture taken during the 1920 Great Depression?; and (4) What effect would analyzing three letters about the same topic have on your historical interpretation? Two trained scorers evaluated each response ($r = .81$) such that a response received one point for each correct answer to each question. Since there were potentially many correct answers to each question, there was no maximum transfer score. A sample of correct answers would include: for Question 1, to increase the validity of an interpretation one could evaluate additional sources to corroborate the current source; for Question 2, the past is difficult to understand since the remaining artifacts only provide limited evidence and are always created for a specific, sometimes unknown, purpose; for Question 3, a photograph could be analyzed using the SCIM strategy (i.e., summarizing the obvious content within the source, contextualizing the photo in time and place, inferring information beyond the immediate source, monitoring oneself for questions and needs); for Question 4, analyzing three letters would provide evidence for corroboration and expand the range of possible relevant inferences.

PROCEDURE

Participants were tested individually at laptop computers, in groups of 1 to 8, in a computer lab with an adjacent hallway. Participants entered the computer lab and were directed to a laptop computer where they logged-in using their university email addresses. After logging-in, participants were given 5 minutes to complete a demographics questionnaire. Upon completion of the demographics questionnaire, participants listened to a 90 second iPod video describing how to locate and select videos/movies and how to adjust the volume on an iPod. The participants in the mobile condition then left the computer room and waited at the starting line of the walking course. At the lab instructor's command, each participant would start the multimedia tutorial and begin the walking course. Upon completion of the multimedia tutorial, participants in the mobile condition would return to the computer lab. Meanwhile, after the participants in the mobile condition left the computer lab, participants in the stationary condition would start the multimedia tutorial while sitting at their desks. After the participants in both groups had completed viewing the multimedia tutorial and returned to the room, all participants were given 10 minutes to complete the strategy recall test. After completing the recall test, participants were given 20 minutes to complete the knowledge transfer test. Finally, all questionnaires, assessments and tests were completed on laptop computers.

RESULTS

This experiment was designed to (a) evaluate the effects of learning in stationary versus mobile learning environments; (b) evaluate the existence of a general WMC effect; and (c) evaluate whether WMC differentially affected performance in stationary and mobile learning environments. These questions were evaluated using two 2 (low WMC, high WMC) x 2 (stationary, mobile) ANOVAs, one for the recall data and one for the transfer data. All post-hoc comparisons involved Tukey analyses with an alpha criterion of 0.05 and all effect size calculations involved Cohen's *d* (Cohen, 1998).

Stationary and Mobile Learning Environments

There was a significant difference in cognitive performance between participants who learned in a stationary learning environment as compared to participants who learned in a mobile learning environment (see Table 1). Specifically, participants in the stationary learning environment recalled more historical inquiry and SCIM strategy components than participants in the mobile learning environment, $F(1,80) = 8.66$, $MSE = 52.03$, $d = 0.72$, $p = .00$. In addition, participants in the stationary learning environment transferred more historical inquiry and SCIM strategy knowledge than participants in the mobile learning environment, $F(1,80) = 7.23$, $MSE = 12.28$, $d = 0.69$, $p = .00$.

Table 1

Means and Standard Deviations for Recall and Transfer Scores for Participants in Stationary and Mobile Learning Environments

	Recall		Transfer	
	M	SD	M	SD
Stationary	6.67*	2.23	5.57*	1.34
Mobile	4.73	3.03	3.97	1.40

Note. Max recall score = 12. Max transfer score = indeterminate.
* $p < .05$

General WMC Effect

The general WMC effect was confirmed for recall as high WMC students recalled more historical inquiry and SCIM strategy components than low WMC students (see Table 2), resulting in a significant main effect for recall, $F(1,80) = 5.97$, $MSE = 35.89$, $d = 0.45$, $p = .01$. Similarly, for transfer, high WMC students generated more valid transfer responses than low WMC students, resulting in a significant main effect for transfer, $F(1,80) = 5.22$, $MSE = 8.86$, $d = 0.43$, $p = .02$. These results are consistent with previous findings regarding a general WMC effect (Doolittle, 2008, Unsworth & Engle, 2007), that high WMC students outperform low WMC students on recall and transfer after engaging in a multimedia tutorial.

Table 2
Means and Standard Deviations for Recall and Transfer Scores for High and Low WMC Participants

	Recall		Transfer	
	M	SD	M	SD
Low WMC	5.41	2.99	4.95	1.68
High WMC	6.60*	2.19	5.55*	0.95

Note. Max recall score = 12. Max transfer score = indeterminate.
* $p < .05$

Differential Effects of WMC on Performance in Stationary and Mobile Learning Environments

While there were significant WMC and learning environment main effects, there were also significant interactions between WMC and learning environment. The significant interaction for recall, $F(1,80) = 5.15$, $MSE = 30.94$, $d = 0.56$, $p = .01$, appears to be based on participants with low WMC in the mobile learning environment recalling less historical inquiry and SCIM strategy components than participants in any other combination of conditions (see Figure 3). This appearance was statistically confirmed using a contrast analysis comparing the mobile-low WMC group to the remaining three groups (mobile-high WMC, stationary-low WMC, stationary-high WMC), $F(1,80) = 6.85$, $MSE = 6.00$, $d = 0.96$, $p < .02$. There was also a significant interaction for transfer, $F(1,80) = 4.22$, $MSE = 7.18$, $d = 0.51$, $p = .04$. This interaction appeared to be the result of participants with low WMC in the mobile learning environment transferring less historical inquiry and

SCIM strategy components than participants in any other combination of conditions (see Figure 4). This appearance was statistically confirmed using a contrast analysis comparing the mobile-low WMC group to the remaining three groups (i.e., mobile-high WMC, stationary-low WMC, stationary-high WMC), $F(1,80) = 11.94$, $MSE = 1.69$, $d = 0.99$, $p < .001$.

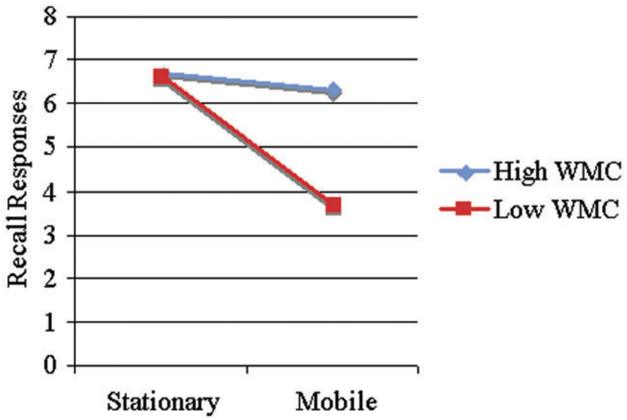

Figure 3. The interaction effects for recall between WMC and instructional environment.

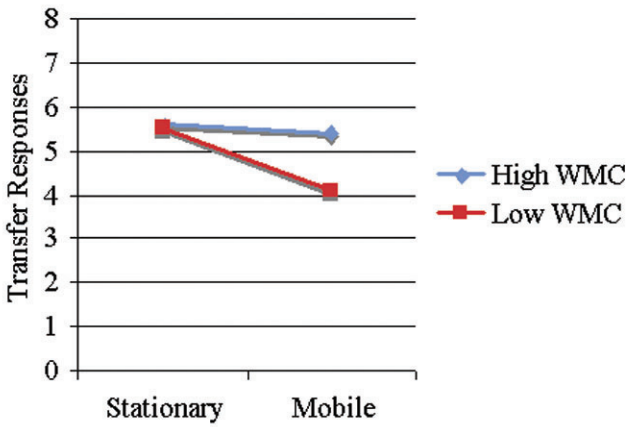

Figure 4. The interaction effects for transfer between WMC and instructional environment.

DISCUSSION

The goal of this research was to determine the effects of learning while mobile, as well as to examine the possibility that individual differences in working memory capacity (WMC) may yield differential learning effects. The study found evidence that learning while mobile was negatively affected in comparison to learning while stationary. Specifically, it was found that students who learned about historical inquiry using a portable digital media player (e.g., iPod), while navigating a walking course that required attention to the path taken, performed significantly more poorly on measures of recall and transfer than students who learned while simply sitting at a desk. These results are in accord with previous findings addressing divided attention (Anderson & Craik, 1974; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). Divided attention refers to the situation in which an individual must attend to two or more stimuli, such as attending to a multimedia tutorial while also attending to a walking path. The literature on divided attention is clear; when attention is divided during the learning or encoding phase of a task, cognitive performance declines (Anderson & Craik, 1974; Baddeley, Lewis, Eldridge, & Thomson, 1984; Fernandes & Moscovitch, 2000). The reason for this decline is that attending to one task, such as navigating the walking course, reduces the amount of attention that is available for a second task, such as engaging in the historical inquiry multimedia tutorial (Craik et al., 1996). According to Craik et al. (1996),

> …taken together, these results [concerning divided attention] suggest that memory encoding processes require attention, that there is a trade-off in this respect between memory and the concurrent task, and that allocation of attention to encoding processes is to some extent under the participant's control. (p. 160)

If, then, as Craik et al. (1996) surmise, "encoding processes require attention," those students with better attentional control should perform better than students with poorer attentional control under conditions of distraction (see also Feldman et al., 2004; Oberauer & Kliegl, 2004). The present study confirmed this relationship. Students with high WMC capacity recalled and transferred more information from the historical inquiry multimedia tutorial than students with low WMC. These findings provide support for a general WMC effect; that is, that students with high WMC will cognitively outperform low WMC students. Support for a general WMC perspective comes from Kane and Engle (2003) who established that general controlled-attention is responsible for the maintenance of information and the avoidance of distraction in complex cognitive tasks. Further, research involving a wide array of tasks that demand attention-control for success (e.g., dichotic-listening task, antisaccade task, Stroop task) have demonstrated a general performance advantage for high WMC students (Conway, Cowan, & Bunting, 2001; Kane & Engle, 2003; Unsworth, Schrock, & Engle, 2004; cf. Kane, Poole, Tuholski, & Engle, 2006).

The present study also established that students with low WMC recalled and transferred less in the mobile learning environment than any other students in any other conditions. It is not at all surprising that those students with the poorest attentional control and most susceptibility to distraction, low WMC students, performed the poorest in the condition that required the greatest amount of attentional control due to the highest level of external distraction, learning while mobile. It is also not surprising that low WMC students performed equally well as high WMC student in the stationary learning environment as the stationary learning environment required only minimal attentional control due to the lack of external distractions.

These results provide evidence that in creating multimedia instructional environments, teachers must consider not only the construction of the multimedia instruction itself, but also the students who will engage in the multimedia instruction and the manner in which the instruction will take place. The present findings suggest that learning while stationary represents an environment in which both high and low WMC students perform equally well, and thus should be encouraged (e.g., as an adjunct to performing a lab experiment where the iPod provides directions and modeling for the completion of the lab). The findings also suggest, however, that learning while mobile is detrimental to some students and thus, as an instructional strategy, "learning while mobile" should be implemented with prudence (e.g., studying for a test, using the iPod, while walking through an airport). Finally, the present study represents somewhat of a blunt instrument in examining the effects of WMC on learning while mobile and thus generalizations must be made with caution. In the future, more nuanced and ecologically valid studies are needed to clarify these initial findings; for example, will low WMC students be disadvantaged when engaging in a museum walking tour that uses a portable digital media player to deliver place-specific content?

CONCLUSION

The present study sought to investigate the interplay between mobile learning and working memory capacity (WMC) based on a multimedia learning task. Given the current interest in education in mobile learning (see Kukulska-Hulme & Traxler, 2005) and multimedia learning (see Mayer, 2005), an investigation into possible individual differences was undertaken.

The current results indicate that students who have poor attentional control, or who are susceptible to external distraction, are likely to be disadvantaged in mobile multimedia learning environments where distractions may be high. As the creation and application of mobile multimedia learning environments moves forward, it is important that individual differences be considered so that a portion of the population is not left behind.

References

Ally, M. (2007). Mobile learning [Special issue]. *International Review of Research in Open and Distance Learning, 8*(2).

Anderson, C., & Craik, F. (1974). The effect of a concurrent task on recall from primary memory. *Journal of Verbal Learning and Verbal Behavior, 13*, 107-113.

Baddeley, A., Lewis, V., Eldridge, M., & Thomson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 13*, 518-540.

Barnes, P., & Goeman, B. (2007). The use of iPod technology in counselor education. In C. Crawford et al. (Eds.), *Proceedings of the Society for Information Technology and Teacher Education International Conference* (pp. 22-27). Chesapeake, VA: AACE.

Belanger, Y. (2005, June). *Duke University iPod fist year experience final evaluation report*. Retrieved July 1, 2007, from http://cit.duke.edu/pdf/ipod_initiative_04_05.pdf

Buehner, M., Krumm, S., & Pick, M. (2005). Reasoning = working memory ≠attention. *Intelligence, 33*, 251-272.

Cantor, J., & Engle, R. W. (1993). Working-memory capacity as long-term memory activation: An individual-differences approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(5), 1101-1114.

Caudill, J. (2007). The growth of m-Learning and the growth of mobile computing: Parallel developments. *International Review of Research in Open and Distance Learning, 8*(2). Retrieved July 1, 2007, from http://www.irrodl.org/index.php/irrodl/article/view/348/913

Cebeci, Z., & Tekdal, M. (2006). Using podcasts as audio learning objects. *Interdisciplinary Journal of Knowledge and Learning Objects, 2*, 47-57.

Chan, A., Lee, M., & McLoughlin, C. (2006). Everyone's learning with podcasting: A Charles Sturt University experience. In L. Markauskaite, P. Goodyear, & P. Reimann (Eds.) *Proceedings of the 23rd Annual Conference of the Australasian Society for Computers in Learning in Tertiary Education: Who's Learning? Whose Technology?* (pp. 111-120). Sydney: Sydney University Press.

Chinnery, G. M. (2006). Going to the MALL: Mobile assisted language learning. *Language Learning & technology, 10*(1), 9-16.

Conway, A. R., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163-183.

Craik, F., Govoni, R., Naveh-Benjamin, M., & Anderson, N. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General, 125*(2), 159-180,

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.

Daneman M., & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Verbal Learning and Verbal Behavior.* 19, 450–466.

Doolittle, P. E., McCloud, J., Byrd, C. N., & Mariano, G. J. (2008). *Working memory capacity, attentional control and multimedia learning.* Paper presented at the annual conference of the Eastern Educational Research Association, Hilton Head, SC.

Fallahkhair, S., Pemberton, L., & Griffiths, R. (2007). Development of a cross-platform ubiquitous language learning service via mobile phone and interactive television. *Journal of Computer Assisted Learning, 23*, 312-325.

Feldman, B., L., Tugade, M. M., & Engle, R. A. (2004). Individual differences n working memory capacity and dual-process theories of the mind. *Psychological Bulletin, 130*(4), 553-573.

Fernandes, M., & Moscovitch, M. (2000). Divided attention and memory: Evidence of substantial interference effects at retrieval and encoding. *Journal of Experimental Psychology: General, 129*(2), 155-176.

Gaultney, J. F., Kipp, K., & Kirk, G. (2005). Utilization deficiency and working memory capacity in adult memory performance: Not just for children anymore. *Cognitive Development, 20,* 205-213.

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15*, 313-331.

Goh, T., & Kinshuk. (2006). Getting ready for mobile learning – adaptation perspective. *Journal of Educational Multimedia and Hypermedia, 15*(2), 175-198.

Harp, S. F., & Mayer, R. E. (1998). How seductive details do their damage. A theory of cognitive interest in science learning. *Journal of Educational Psychology, 90*, 414-434.

Just, M., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122-149.

Kadirire, J. (2007). Instant messaging for creating interactive and collaborative m-Learning environments. *International Review of Research in Open and Distance Learning, 8*(2). Retrieved July 1, 2007 from http://www.irrodl.org/index.php/irrodl/article/view/344/881

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13*, 351-371.

Kane, M. J., Bleckley, M. K., Conway, A. R., & Engle, R. W., (2001). A controlled-attention view of working memory capacity. *Journal of Experimental Psychology: General, 130*(2), 169-183.

Kane, M. J., & Engle, R. W., (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132*(1), 47-70.

Kane, M. J., Hambrick, D. Z., Tuhoski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning, *Journal of Experimental Psychology: General, 133*(2), 189-217.

Kiewra, K. A., & Benton, S. L. (1988). The relationship between information-processing ability and notetaking. *Contemporary Educational Psychology, 13,* 33-44.

Kukulska-Hulme, A. (2007). Mobile usability in educational contexts: What have we learnt? *International Review of Research in Open and Distance Learning, 8*(2). Retrieved July 1, 2007, from http://www.irrodl.org/index.php/irrodl/article/view/356/907

Kukulska-Hulme, A., & Traxler, J. (2005). *Mobile learning: A handbook for educators and trainers.* London: Routledge.

Lai, C., Yang, J., Chen, F., Ho, C., & Chan, T. (2007). Affordances of mobile technologies or experiential learning: The interplay of technology and pedagogical practices. *Journal of Computer Assisted Learning, 23*, 326-337.

Laouris, Y., & Eteokleous, N. (2005). *We need an educationally relevant definition of mobile learning.* Paper presented at the mLearn2005: 4th World Conference on mLearning, Cape Town, South Africa.

La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 1118-1133.

Liu, C., & Kao, L. (2007). Do handheld devices facilitate face-to-face collaboration? Handheld devices with large shared display groupware to facilitate group interactions. Journal of Computer Assisted Learning, 23, 285-299.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*(2), 199-207.

Maag, M. (2006). iPod, uPod? An emerging mobile learning tool in nursing education and students' satisfaction. Proceedings of the 2006 ascilite conference, Australia.

Massey, A., Ramesh, V., & Khatri, V. (2006). Design, development, and assessment of mobile applications: the case for problem-based learning. *IEEE Transactions on Education, 49*(2), 183-192.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2), 377-389.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge, UK: Cambridge University Press.

Mayer, R. E. (Ed.) (2005). *The Cambridge Handbook of Multimedia Learning*. Cambridge: Cambridge Press.

Mayer, R., & Jackson, J. (2005). The case for coherence in scientific explanations: Quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology: Applied, 11*(1), 13-18.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*(2), 312-320.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81-97.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*(2), 358-368.

Ollerenshaw, A., Aidman, E., & Kidd, G. (1997). Is an illustration always worth ten thousand words? Effects of prior knowledge, learning style, and multimedia illustrations on text comprehension. *International Journal of Instructional Media, 24*, 227-238.

Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2006). *Literature review in mobile technologies and learning* (Report 11). Bristol, UK: Futurelab.

Pedersen, J., & Marek, E. (2007). Technology integration: PDAs as an instructional and reflective tool in the science classroom. *Contemporary Issues in Technology and Teacher Education, 7*(1), 521-528.

Pratt, M.W., Boyes, C., Robins, S., & Manchester, J. (1989). Telling tales: Aging, working memory, and the narrative cohesion of story retellings. *Developmental Psychology, 25*, 628-63.

Rekkedal, T., & Dye, A. (2007). Mobile distance learning with PDAs: Development and testing of pedagogical and system solutions supporting mobile distance learners. *International Review of Research in Open and Distance Learning, 8*(2). Retrieved July 1, 2007, from http://www.irrodl.org/index.php/irrodl/article/view/349/883

Sanchez, C. A., & Wiley, J. (2006). An examination of the seductive details effect in terms of working memory capacity. *Memory & Cognition, 34*(2), 344-355.

Seppala, P. & Alamaki, H. (2003). Mobile learning in teacher education. *Journal of Computer Assisted Learning, 19*, 330-335.

Sharples, M. (2007). Mobile learning [Special issue]. *Journal of Computer Assisted Learning, 23*.

Smordal, O., & Gregory, J. (2003). Personal digital assistants in medical education and practice. *Journal of Computer Assisted Learning, 19*, 320-329.

Shute, V. J. (1991). Who is likely to acquire programming skills? *Journal of Educational Computing Research, 7*, 1-24.

Thornton, P., & Houser, C. (2004). Using mobile phones in education. *Proceedings of the 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education,* 3-10.

Traxler, J., & Kukulska-Hulme, A. (2005). *Evaluating mobile learning: Reflections on current practice.* Paper presented at the mLearn2005: 4th World Conference on mLearning, Cape Town, South Africa.

Trelease, R. (2006). Diffusion of innovations: Anatomical informatics and iPods. *The Anatomical Record (Part B: New Anatomy), 289B*, 160-168.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154.

Unsworth, N. & Engle, R. W. (2007). The nature of individual difference n working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*(1), 104-132.

Vavoula, G., & Sharples, M. (2002). KLeOS: A personal, mobile, knowledge and learning organisation system. *Proceedings of the IEEE International Workshop on Mobile and Wireless Technologies in Education*, Vaxjo, Sweden, 52-156.

Watanabe, Y., & Akahori, K. (2007). Development of iPod usable contents for teacher education program. In C. Crawford et al. (Eds.), *Proceedings of the Society for Information Technology and Teacher Education International Conference* (pp. 548-553). Chesapeake, VA: AACE.