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Building a memory palace in minutes: Equivalent memory performance using virtual versus conventional environments with the Method of Loci

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ABSTRACT

The Method of Loci (MOL) is an ancient mnemonic strategy used to enhance serial recall. Traditionally, the MOL is carried out by imagining navigating a familiar environment and "placing" the to-be-remembered items in specific locations. For retrieval, the mnemonist re-imagines walking through the environment, "looking" for those items in order. Here we test a novel MOL method, where participants use a briefly studied virtual environment as the basis for the MOL and applied the strategy to 10 lists of 11 unrelated words. When our virtual environments were used, the MOL was as effective, compared to an uninstructed control group, as the traditional MOL where highly familiar environments were used. Thus, at least for naïve participants, a highly detailed environment does not support substantially better memory for verbal serial lists.
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1. Introduction

Since the ancient Greeks, mnemonic techniques have been used to facilitate accurate recollection of information when external sources of reference were unavailable (Yates, 1966). Of the large number of existing mnemonic strategies, one of the oldest and most effective is the Method of Loci (MOL; also known as the 'memory palace' technique, Spence, 1984). Despite its popularity for personal use (Foer, 2011; Maguire, Valentine, Wilding, & Kapur, 2003; Raz et al., 2009), the mechanisms underlying the effectiveness of the MOL are not well understood and there are only a modest number of published studies investigating this strategy. An important limitation of research into the MOL is that effective use of the MOL traditionally requires extensive training (e.g., two 1-hour training sessions, Brehmer, Li, Müller, von Oertzen, & Lindenberger, 2007; three 40-minute training sessions, Bower & Reitman, 1972; 4 to 6 h of training with older adults, Brooks, Friedman, & Yesavage, 1993; two training and 6 adaptive practice sessions, each lasting 1–1.5 h, prior to testing, Kliegl, Smith, & Baltes, 1989, 1990; three 2-hour training sessions, Moé & De Beni, 2005; one session of training and asked to practice overnight and the next day prior to testing, Roediger, 1980) and the use of personally familiar environments that cannot be controlled across participants (e.g., Brooks et al., 1993; Cornoldi & De Beni, 1991; Massen & Vaterrodt-Plünnecke, 2006; Roediger, 1980). Our first goal was to design a more controlled experimental approach for MOL research. We ask whether using a briefly presented virtual environment as one's set of loci is equivalent to the conventional method of using the memory of a personally familiar location, usually one's home. Specifically, we test (a) whether participants will be able to use a briefly presented, non-personal environment for the MOL, (b) whether the MOL is exceptionally effective for remembering items in order compared to uninstructed controls, and (c) whether the MOL is particularly specialized, compared to uninstructed controls, for remembering highly imageable words. We also manipulate the spatial layout of our virtual environments (apartment, school, or warehouse) to test whether the MOL depends on specific topology or spatial characteristics.

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1.1. MOL: past and present

The MOL has traditionally been used as a method for remembering speeches and lists of items, for which the order of information is important (Yates, 1966; also see Madan & Singhal, 2012a). In its traditional form, the MOL requires the user to imagine walking through a familiar environment and placing the to-be-remembered items along their path. To recall, they re-imagine walking through the environment, seeking items as they go.

The MOL is still one of the most utilized strategies for world-class mnemonists trying to remember exceptionally large amounts of information quickly (e.g., Foer, 2011; Maguire et al., 2003; Raz et al., 2009). Furthermore, the MOL has been investigated, with some success, as a possible aid for memory-impaired individuals (Richardson, 1995; Tate, 1997) and to address memory decline in healthy aging adults (Yesavage, 1983). Additionally, the MOL has been used as a tool for investigating memory plasticity and episodic memory performance across the lifespan, from children as young as 9 years of age to adults over the age of 65 (Baltes & Lindenberger, 1988; Brehmer et al., 2008; Brehmer et al., 2007; Kliegl, Smith, & Baltes, 1986; Kliegl et al., 1989, 1990).

Research on the MOL is challenging due to the MOL's reliance on individualistic and internal processes (i.e., *imagining oneself* traveling through a *personally familiar* environment). Some researchers have addressed this problem by either giving participants a standardized sequence of pictures along a navigated path (Bower & Reitman, 1972; Moé & De Beni, 2005) or a set of spatially related images (e.g., 30–40 nearby landmarks, Kliegl et al., 1986, 1989, 1990; Lindenberger, Kliegl, & Bates, 1992) to memorize and use as loci prior to testing. However, these procedures diverge from the traditional MOL method as they lack many aspects of movement through an environment (e.g., spatial contiguity, optic flow, self-directed navigation) and require extensive training prior to testing (e.g., Bower & Reitman, 1972; Brooks et al., 1993; Kliegl et al., 1986, 1989, 1990; Moé & De Beni, 2005; Roediger, 1980). We address these issues by having participants navigate a virtual environment, with first-person video-game levels of detail in visual movement cues (e.g., optic flow and visual detail), for a very short period of time (maximum of 5 min), just prior to applying MOL with the environment to serial recall (similar first-person video games have been used extensively in research on spatial navigation and localization; e.g., Caplan et al., 2003; Kelly & Gibson, 2007; Legge et al., 2012; Newman et al., 2007; Sturz, Bodily, Katz, & Kelly, 2009; Talbot, Legge, Bulitko, & Spetch, 2009; Watrous, Fried, & Ekstrom, 2011).

1.2. Outline and predictions of the current study

Participants were assigned to one of three groups: (a) instructed to use the conventional MOL substrate, a very familiar environment such as their house (cMOL); (b) instructed to use a pre-exposed virtual environment (vMOL); (c) and a control group, uninstructed on study and recall strategy (CON). All groups received equivalent experience with the virtual environments prior to testing and only minimal instruction on how to use the MOL (cMOL and vMOL groups). We predicted that the MOL should be most effective when used memories of with rich, highly detailed environments that have been learned via real navigation (cMOL). However, we also predicted that, even in a non-conventional form (vMOL), the MOL procedure should allow participants to have higher levels of recall accuracy than uninstructed participants. Thus, we predicted cMOL > vMOL > CON in accuracy.

To evaluate serial recall performance, we analyzed our data in two ways to test the hypothesis that the MOL is specialized for memory for order: (a) strict scoring (accuracy calculated as the number of items recalled in the *correct* list position) and (b) lenient scoring (accuracy calculated as the number of list-items remembered, *regardless of output order*). Since the MOL is supposed to be particularly effective at storing and recovering items in order, we predicted that the relative advantage of cMOL over vMOL, and vMOL over CON, would be even more pronounced for strict than for lenient scores of serial recall. Related to this, the MOL has also been thought to become less effective as the number of lists increases (De Beni & Cornoldi, 1988; Massen & Vaterrodt-Plünnecke, 2006). This has been hypothesized to be due to a buildup of proactive interference caused by using the same environment many times. Additionally, because the MOL is a complex strategy and novel to most participants, it is possible that participants' accuracy may improve as they gain experience with the MOL. Thus, we may observe a significant increase in accuracy as participants proceed through the experiment (i.e., list number increases), thus demonstrating a significant practice effect.

Further, high-imageability words are recalled significantly more accurately than low-imageability words in serial recall (Allen & Hulme, 2006; Paivio, 1971; Walker & Hulme, 1999). Due to the MOL's reliance on mental imagery, it has been suggested that MOL, like other imagery-based strategies, is specialized for highly imageable words (Crowder, 1976; De Beni & Cornoldi, 1985). We therefore manipulated the imageability of the word lists and tested the hypothesis that imageability should interact with group such that the high-imageability advantage should be greater for the MOL groups than CON.

Finally, given that our participants were naïve, rates of compliance with MOL may indicate whether vMOL or cMOL might be more effective for memory enhancement or compensation training. We therefore tested whether compliance rates differ between vMOL and cMOL.

2. Method

2.1. Participants

A total of 142 undergraduate students, aged 17–27 ($M = 19.13$, $SD = 1.69$; 88 females)[4] participated for partial credit in an introductory psychology course at the University of Alberta. Participants were required to have English as their first language, have normal or corrected-to-normal vision, and be comfortable typing. Written informed consent was obtained and continued participation was voluntary. Participants signed-up for the experiment via an online system and were automatically assigned to a group (cMOL, vMOL, or CON) based on the order of their sign-up (see Table 1 for detailed descriptive statistics for the participants in each group). All procedures were approved by a Research Ethics Board at the University of Alberta.

2.2. Materials

Tasks were presented with an iMac (model: 5.1) computer with a 15″ screen (resolution: 1440 × 900 pixels).

Four virtual environments were created using the Hammer editor and Half-life 2 object library (Valve Corp.; Bellevue, WA). Virtual environments were compiled and ran using the Source engine (Valve Corp.; Bellevue, WA). One environment was an empty, square room used to initially train participants to navigate using the keyboard and mouse. The other three environments were modeled after three real-world environments: an apartment, a school, and a warehouse (see Fig. 1 and videos in supplementary materials).

Lists for serial recall were constructed from the high-imageability word pool and the low-imageability word pool used by Madan, Glaholt, and Caplan (2010). Each word pool contained 110 English words, each 4–6 letters in length, and both pools were matched for several orthographical and phonological word properties (Madan et al., 2010). For

[4] One participant was excluded from our analyses because he/she was above 30 years of age. We excluded this participant, as the MOL has been shown to be less effective for older individuals (Brehmer et al., 2007, 2008; Brooks et al., 1993; Kliegl et al., 1989, 1990; Lindenberger et al., 1992).

Table 1
Age and gender descriptive statistics for each instruction group.

	All-inclusive				Compliant-only			
	N	Females	M_{age}	SD_{age}	N	Females	M_{age}	SD_{age}
CON	48	31	19.77	6.10	37	23	18.89	1.56
cMOL	48	29	19.17	1.83	19	13	18.58	0.90
vMOL	47	29	19.30	1.78	27	18	19.67	1.92

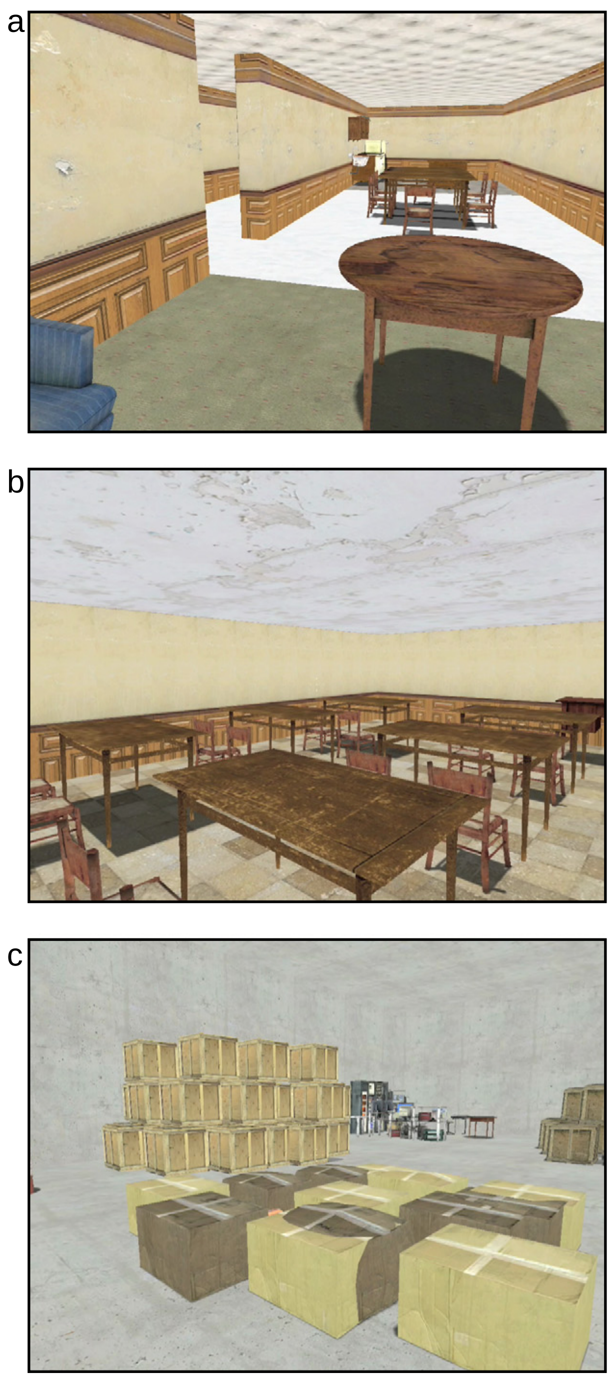

Fig. 1. Screenshots of the three virtual environments used: (a) house; (b) school; (c) warehouse. Videos showing each environment in its entirety can be viewed in supplementary materials.

each list, words were randomly selected from the appropriate pool without replacement. The serial recall phase was implemented with the Python experiment-programming library (pyEPL; Geller, Schleifer, Sederberg, Jacobs, & Kahana, 2007).

2.3. Procedure

The experimental session for all groups consisted of a practice phase, a virtual environment exploration phase, and a serial recall phase (Fig. 2).

In the practice phase, participants were placed in a virtual training room and instructed to use the keyboard and mouse for navigation and orientation. After participants announced that they were confident in their navigational ability, they advanced to a practice serial recall task where they were instructed to study and then recall one list of 11 words. The words were presented to participants sequentially and centrally on the screen for 5000 ms with an inter-stimulus interval of 150 ms. After the list was presented, participants were asked to recall the list in order by typing the words. Words were entered one at a time, each followed by the "Enter" key. Upon submission of a word, the screen was cleared and the participant could enter the next response. If participants could not remember a specific word, they could type "PASS" to skip the current serial position. Participants could not view or change any previously entered words. A maximum of 120 s were given for serial recall but was cut short if the participant made 12 responses (12 was used rather than 11 to accommodate errors).

Next, participants were assigned to one of three virtual environments: an apartment, a school, and a warehouse, and were verbally instructed to explore the environment thoroughly within the gaming interface for a maximum of 5 min.

After exploring the virtual environment, participants received instructions that depended on their group assignment. Note that nothing else differed across groups. In both Method of Loci groups (cMOL and vMOL), participants were given a detailed description the Method of Loci strategy, adapted from Yates (1966, p. 2–3; see Appendix). The cMOL group was asked to imagine and use a very familiar environment, such as their home with the MOL. The vMOL group was asked to use the virtual environment they had just finished exploring with the MOL. Participants in the CON group were not instructed to use a particular strategy.

The serial recall phase consisted of 10 lists of 11 unrelated words each, with 5 lists composed of high-imageability words and the other 5 composed of low-imageability words. High- and low-imageability lists were presented in alternating sequence (i.e., H–L–H–L–…) and imageability of the first list was counterbalanced across participants. Other than these differences, the procedure of the serial recall phase followed that of the serial recall task in the practice phase.

At the end of the session, participants were given a questionnaire asking them to report their demographic information, describe the strategy they had used, and indicate whether they had knowledge of the MOL strategy before they started the experiment.

2.4. Data analysis

Analyses were conducted using repeated-measures ANOVAs and *t*-tests in SPSS v19 (IBM Corp.; Somers, NY). Cohen's d effect sizes were computed using G*Power v3 (Faul, Erdfelder, Lang, & Buchner, 2007). Effects were considered significant based on an alpha level of 0.05 and effects not reported were non-significant. Non-significant 'trend' effects ($p<.1$) are also reported.

First we analyzed compliance rate as a function of group. Participants were considered compliant if, on the questionnaire, they reported using the instructed strategy for 50% or more of the lists. Compliance rates were 19/48 (39.6%), 27/47 (57.4%), and 37/47 (78.7%) for cMOL, vMOL, and CON groups, respectively. Note that some participants from the CON group spontaneously reported using the MOL for more

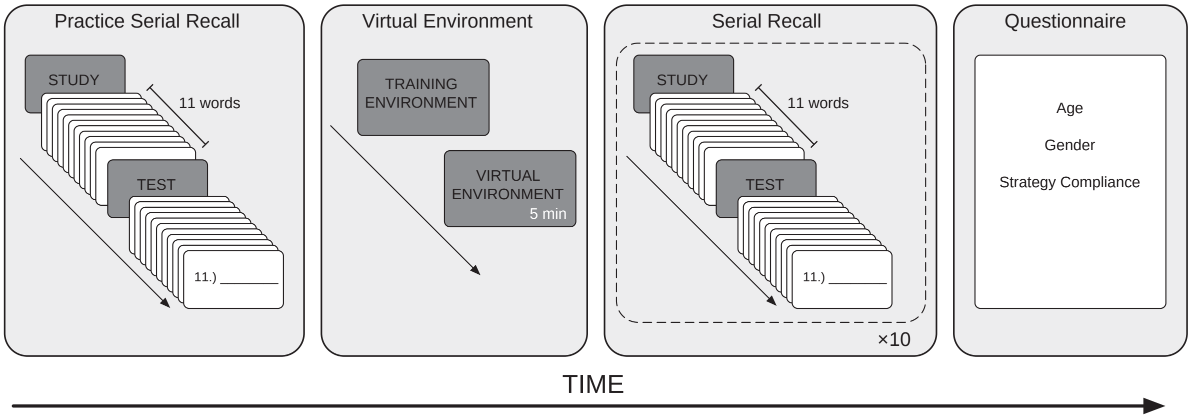

Fig. 2. Task design.

than 50% of the lists and were thus treated as non-compliant for analysis purposes[5].

For the remaining analyses, two sets of analyses were conducted: (a) one with participants grouped according to their original group assignment ('all-inclusive'), and (b) one with participants excluded if they were non-compliant. Two measures of serial recall were used: (a) strict scoring, items-in-position, and (b) lenient scoring, items from the just-studied list, regardless of order. Our dependent measure was accuracy, measured as the proportion of correct responses out of the total number of responses. Analyses were conducted using three-factor mixed-effects ANOVAs with Group (cMOL, vMOL, CON) as a between-subjects factor and Imageability (high, low) and List Number (1–5, nested within Imageability) as within-subjects factors. List Number was included as a factor to determine whether participant's accuracy increased over lists.

When conducting post-hoc tests on significant Group effects, *t*-tests were Bonferroni-corrected. Post-hoc tests on significant List Number and List Number × Imageability interactions compared linear regression slopes relative to zero to determine whether participants became significantly better (or worse) as the experiment progressed.

3. Results

3.1. Preliminary analyses

An initial chi-square test was conducted to compare the compliance rates of participants in cMOL group to those in the vMOL group. Participants in the vMOL group were significantly more likely to adhere to their instructed strategy than those in the cMOL group. Specifically, vMOL participants were compliant for 58.8% of lists, whereas the cMOL group was only compliant for 44.8% of lists. Using the number of participants that were compliant for more than 50% of the lists, we found significantly higher rates of compliance for the vMOL than for the cMOL group [$\chi^2(1, N=48)=5.42$, $p<0.02$, Pearson's $\Phi=.34$]. This suggests that the virtual environment was not significantly more difficult to use with the MOL than a personally familiar environment, and to the contrary, the MOL may be easier to use with the vMOL protocol.

Additionally, we compared age and gender distributions of participants in the all-inclusive and compliant-only data subsets. Tests revealed no significant differences in the distribution of participants in age or gender between all-inclusive and compliant-only data subsets [$p>0.05$]. Thus, any differences observed between analyses conducted on all-inclusive vs. compliant-only data could not be attributed to a different distribution of participants' age or gender.

We compared the number of participants who reported having prior knowledge of the MOL before taking part in the experiment. A chi-square and revealed a trend towards there being an unequal number of participants across groups who reported having previous knowledge of the MOL ($\chi^2(2, N=141)=5.69$, $p<0.06$, Cramer's $\Phi=.12$). Specifically, the CON group had the fewest number of participants who reported having previous knowledge of the MOL (12.77%) when compared to the cMOL (35.42%) and vMOL (34.78%) groups. However, this difference in prior knowledge is most likely an artifact of the detailed description and instruction in the MOL that participants in the cMOL and vMOL groups had compared to the much smaller description the CON participants received in the questionnaire at the end of the experiment. This difference between participants who reported prior knowledge should not have influenced our results, as in the "compliant-only" analyses, all CON participants who reported using the MOL during the experiment were excluded from the dataset.

Furthermore, we initially included the virtual environment participants experienced (apartment, school, warehouse) as a between-subjects factor. However, analyses revealed no significant main effects or interactions with environment using either scoring method [strict- and lenient-scoring: both $p>0.1$]. Furthermore, a chi-square test revealed no effect of environment on task compliance [$p>0.1$]. Thus, environment was not included as a factor in the analyses we report below.

3.2. All-inclusive analysis

3.2.1. Strict-scoring

A significant main effect of Imageability [$F(1,139)=132.05$, $p<0.001$, $\eta_p^2=0.49$] found high-imageability words to be better recalled than low-imageability words (Figs. 3a, 4a–b, 6a–b). A weak, but significant Imageability × List Number interaction was also found [$F(4,540)=2.54$, $p<0.05$, $\eta_p^2=0.02$]. A linear regression on List Number for high-imageability lists had a significant positive slope [$t(142)=2.85$, $p<0.01$,

[5] Participants in our CON group may have been more likely to use the MOL than the average participant because they were taking an introductory psychology course where they may have already learned about the strategy and its effectiveness in list memorization tasks. Participants in the CON group may also have been predisposed to use the MOL more than the average participant because we trained *all* of our participants with the virtual environment prior to the serial recall phase. However, these participants likely used a different version of the MOL than our cMOL and vMOL participants as they were not given specific instructions as to how to use the MOL (see Appendix). Thus, these participants were treated as non-compliant for analysis purposes and excluded from the compliant-only analyses to avoid a potential confound with cMOL and vMOL groups.

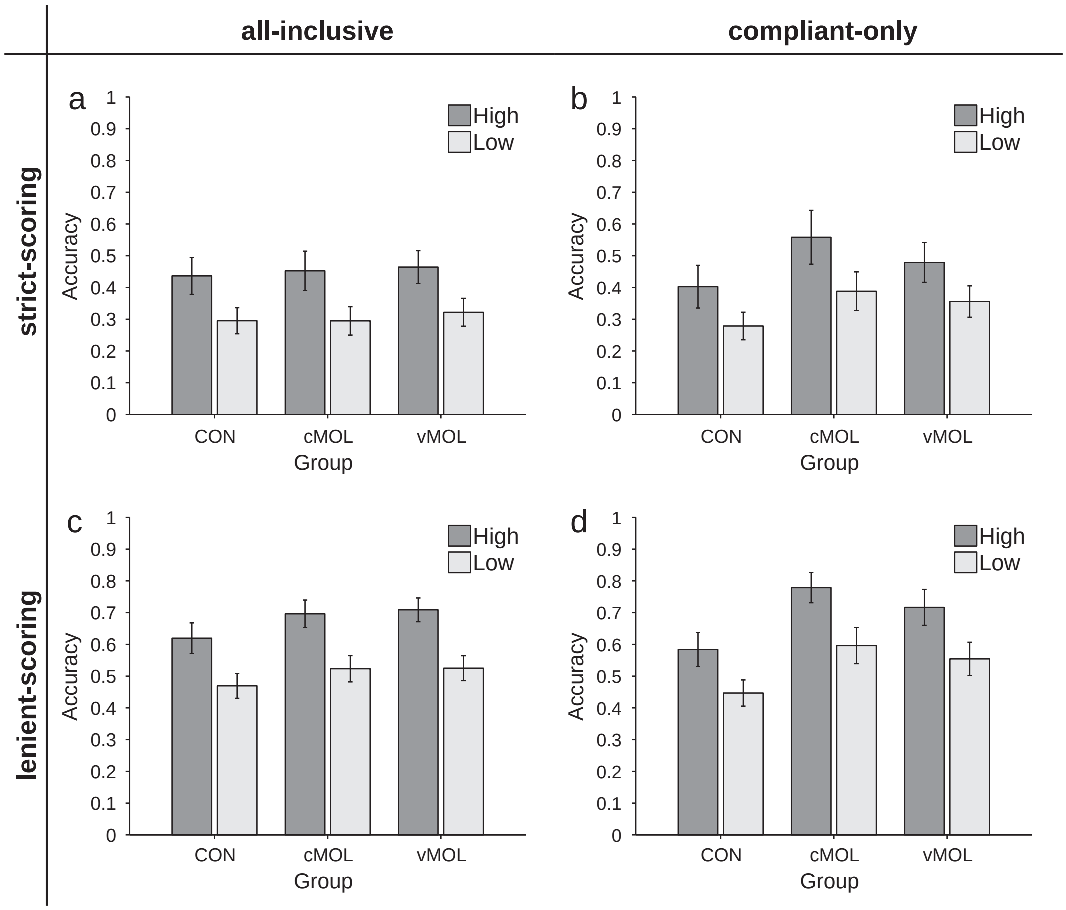

Fig. 3. Serial recall accuracy based on both all-inclusive and compliant-only inclusion criteria for both (a–b) strict-scoring and (c–d) lenient-scoring methods. Error bars are 95% confidence intervals, corrected for individual differences.

Cohen's $d = 0.25$], but the regression for low-imageability lists had a non-significant slope [$p > 0.1$]. Thus, performance improved with practice for high- but not low-imageability lists. We did not observe a significant Imageability × Group interaction [$p > 0.1$, $\eta_p^2 = 0.002$]. We also observed a trend towards a main effect of List [$F(4,540) = 2.07$, $p < 0.1$, $\eta_p^2 = 0.02$]. Contrary to our hypothesis, this trend indicated that participants' accuracy increased along with the number of lists presented. There was no evidence of a List × Group interaction [$p > 0.6$, $\eta_p^2 = 0.01$].

3.2.2. Lenient-scoring

A significant main effect of Imageability [$F(1,139) = 308.32$, $p < 0.001$, $\eta_p^2 = 0.69$] found that high-imageability lists were remembered better than low-imageability lists (Figs. 3c, 4c–d, 6c–d). Analyses also revealed a weak, but significant main effect of Group [$F(2,139) = 4.18$, $p < 0.05$, $\eta_p^2 = 0.06$]. Post-hoc tests revealed that participants in both the cMOL and vMOL groups recalled words better than those in the CON group; however, the difference was only a trend effect when comparing cMOL to CON [Mean Difference (cMOL − CON) = 0.07, SE = 0.03, $p < 0.10$, $d = 0.24$; Mean Difference (vMOL − CON) = 0.07, SE = 0.03, $p < 0.05$, $d = 0.27$]. The vMOL and cMOL groups did not differ from one another [Mean Difference (cMOL − vMOL) = −0.007, SE = 0.03, $p > 0.1$, $d = 0.03$]. As the comparison between recall performance between the cMOL and vMOL groups is of particular interest, we additionally conducted a post-hoc power analysis. Here we directly tested for our ability to detect a medium-size effect ($d = 0.50$, as suggested by Cohen, 1988) of better recall in the cMOL group than in the vMOL group, and thus used a one-tailed comparison. We determined our power ($1 - \beta$) for this analysis to be 0.78, suggesting that we indeed had sufficient power to detect a significant effect of conventional versus virtual MOL protocols.

Finally, we also observed a weak but significant Imageability × List Number interaction [$F(4,538) = 2.59$, $p < 0.05$, $\eta_p^2 = 0.02$]. Linear regressions found that neither high- or low-imageability lists had slopes significantly different from zero [$p > 0.1$]. We did not observe a significant Imageability × Group interaction [$p > 0.1$, $\eta_p^2 = 0.02$], a significant main effect of list [$p > 0.6$, $\eta_p^2 = 0.004$], or a significant List × Group interaction, [$p > 0.5$, $\eta_p^2 = 0.01$].

3.3. Compliant-only analysis

3.3.1. Strict-scoring

A significant main effect of Imageability [$F(1,80) = 62.43$, $p < 0.001$, $\eta_p^2 = 0.44$] found that high-imageability lists were recalled better than low-imageability lists (Figs. 3b, 5a–b, 7a–b). A significant main effect of Group [$F(2,80) = 6.55$, $p < 0.01$, $\eta_p^2 = 0.14$] was explained by post-hoc tests as both the cMOL and vMOL groups recalling significantly more words than the CON group [Mean Difference (cMOL − CON) = .14, SE = 0.04, $p < 0.01$, $d = 0.47$; Mean Difference (vMOL − CON) = 0.10, SE = 0.04, $p < 0.05$, $d = 0.33$]. Accuracy in the cMOL and vMOL groups did not differ from one another [Mean Difference (cMOL − vMOL) = 0.04, SE = 0.05, $p > 0.1$, $d = 0.13$]. We did not observe a significant Imageability × Group interaction [$p > 0.1$, $\eta_p^2 = 0.01$], a significant main effect of list [$p > 0.6$, $\eta_p^2 = 0.01$], or a significant List X Group interaction, [$p > 0.4$, $\eta_p^2 = 0.02$].

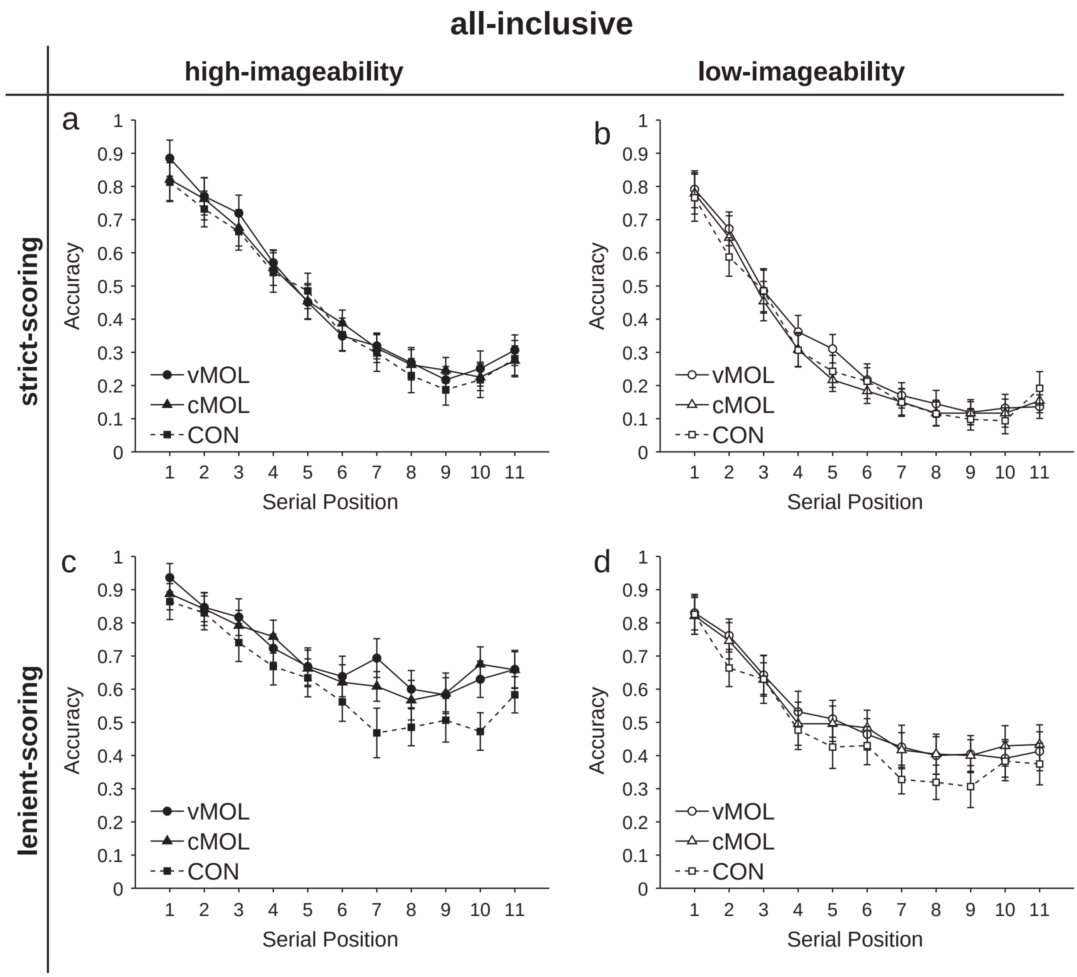

Fig. 4. Serial position curves for the all-inclusive analyses, separately for high- and low-imageability lists. Accuracy analyses were conducted based on both (a–b) strict-scoring and (c–d) lenient-scoring. Error bars are 95% confidence intervals, corrected for individual differences.

Here we again conducted a power analysis, but as one would expect, due to a significantly smaller sample size than our all-inclusive analyses, our statistical power was markedly weaker ($1-\beta=0.50$). Nonetheless, our observed effect size was still larger in magnitude than the small-size effect ($d=0.20$) suggested by Cohen (1988).

3.3.2. Lenient-scoring

A significant main effect of Imageability [$F(1,80)=164.86$, $p<0.001$, $\eta_p^2=0.67$] revealed that high-imageability words were remembered better than low-imageability words (Figs. 3d, 5c–d, 7c–d). A significant main effect of Group [$F(2,80)=12.72$, $p<0.001$, $\eta_p^2=0.24$] was explained by post-hoc tests as both the cMOL and vMOL groups performing significantly better than the CON group [Mean Difference (cMOL−CON)=0.16, SE=0.04, $p<0.001$, $d=0.62$; Mean Difference (vMOL−CON)=0.13, SE=0.03, $p<0.001$, $d=0.49$]. The cMOL and vMOL groups did not differ from one another [Mean Difference (cMOL−vMOL)=0.03, SE=0.04, $p>0.1$ $d=0.12$]. We did not observe a significant Imageability×Group interaction [$p>0.1$, $\eta_p^2=0.038$], a significant main effect of List [$p>0.9$, $\eta_p^2=0.001$], or a significant List×Group interaction, [$p>0.2$, $\eta_p^2=0.03$].

Our power analysis conducted for the strict-scoring analysis in Section 3.2.1. applies identically here ($1-\beta=0.50$), and again we found our effect size to be markedly larger than the small-size effect ($d=0.20$) suggested by Cohen (1988).

4. Discussion

We asked four main questions: first, how would memory performance with the Method of Loci using a briefly studied virtual environment (vMOL) compare to using a personally familiar environment for the MOL (cMOL)? Second, would the MOL interact with imageability? Third, is the MOL is particularly specialized for remembering serially ordered information? Fourth, will compliance rates differ between cMOL and vMOL protocols, allowing us to determine whether one MOL protocol is more effective for memory enhancement and compensation training than the other?

Our results demonstrate that our virtual protocol for the MOL was not significantly different from the conventional MOL strategy, even though it lacks many of the presumed requirements for effective use of the MOL (e.g., by not using a familiar, richly detailed environment, very little training). As demonstrated by the near-zero magnitude of effect sizes for vMOL to cMOL comparisons, we found no difference between vMOL and cMOL groups in recall accuracy with both strict and lenient scoring methods. Additionally, although we replicate previous findings showing that high-imageability words are recalled more accurately than low-imageability words (Allen & Hulme, 2006; Paivio, 1971; Walker & Hulme, 1999), we found no interaction between imageability and strategy. This lack of an interaction between imageability and strategy is both novel and surprising. Specifically, due to the MOL relying heavily on mental imagery, we hypothesized that high-imageability

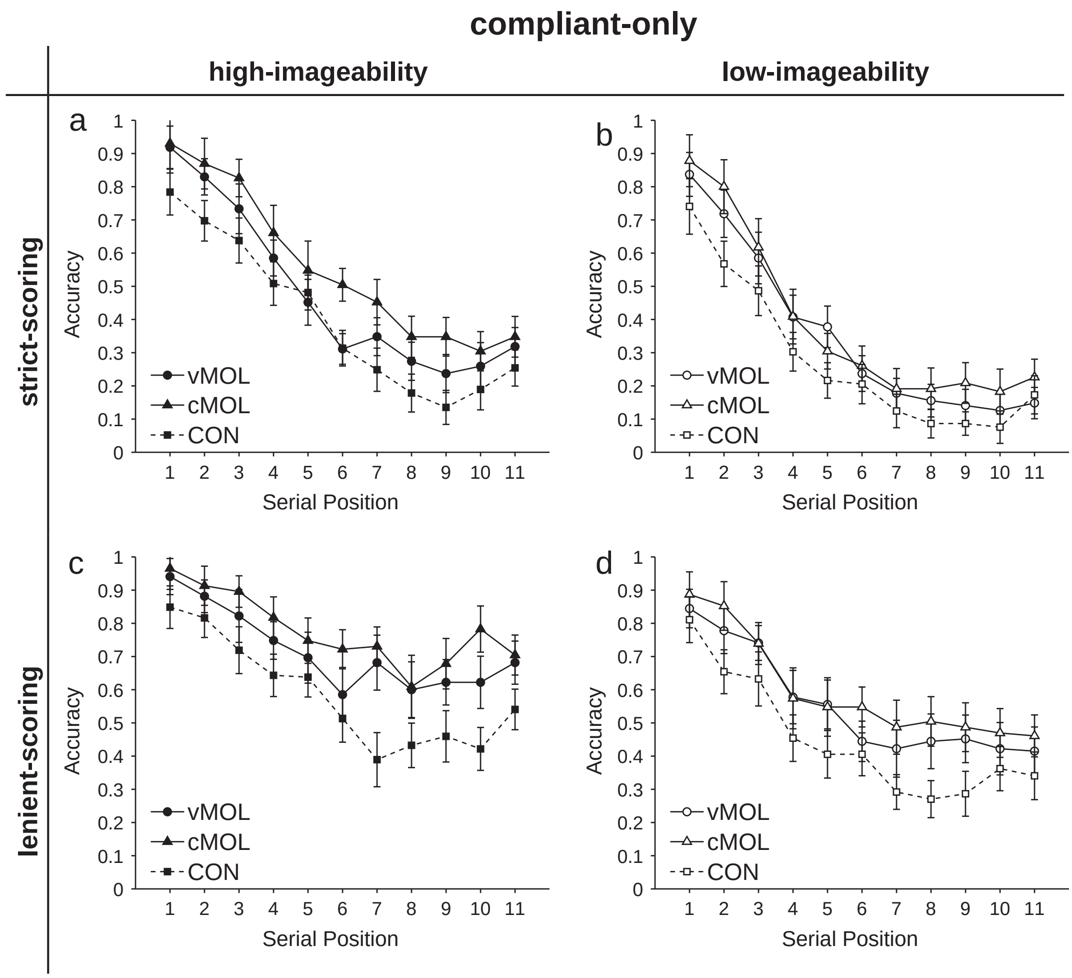

Fig. 5. Serial position curves for the compliant-only analyses, separately for high- and low-imageability lists. Accuracy analyses were conducted based on both (a–b) strict-scoring and (c–d) lenient-scoring. Error bars are 95% confidence intervals, corrected for individual differences.

words would be recalled more accurately than low-imageability words. Additionally, we did not find evidence that the MOL is particularly effective for remembering serially ordered information compared to uninstructed controls. Each of these findings, as well as others, will be discussed in more detail below.

4.1. Virtual environments as a tool for systematic investigation of MOL

Previous studies investigating the MOL faced a methodological challenge by investigating a mnemonic strategy that relies heavily on a personally chosen environment, leading to a lack of experimental control. In an attempt to develop a more controllable protocol for researchers investigating the MOL, we had participants use a virtual environment as the basis for the MOL (vMOL). We then compared participants' accuracy to those using a conventional MOL protocol (cMOL) and an uninstructed control (CON). We hypothesized that participants' recall accuracy would be best for participants using cMOL, followed by participants using vMOL, with CON participants having the worst recall accuracy. Deviating from our initial hypothesis, we found that, while participants using both cMOL and vMOL groups had significantly higher levels of recall than uninstructed participants, they did not differ from one another. Furthermore, due to several near-zero magnitude effect sizes for comparisons between vMOL and cMOL, it is unlikely that the there are any differences in effectiveness for the two MOL protocols.

When we analyzed the data either based on the group to which participants had been assigned ('*all-inclusive analysis*'), or based on only compliant participants ('*compliant-only analysis*'), we found that both cMOL and vMOL groups were significantly more accurate in recalling items (lenient-scoring) as well as items in order (strict-scoring) than those who were uninstructed on strategy (CON). Specifically, participants in the cMOL and vMOL groups were between 10 and 16% more accurate in their responses than those who were uninstructed (see Sections 3.2 and 3.3). Thus, our results indicate that cMOL and vMOL protocols significantly increased overall item recall, as well as ordered recall. However, it should be noted that effect sizes were always smaller in magnitude for vMOL than cMOL comparisons, relative to the CON group. We hypothesize that this reduced effect size is due to the relatively small amount of experience with the virtual environment that vMOL participants had. As participants in the cMOL group used personally familiar environments, they may have had a slight, but not statistically significant, advantage over vMOL participants. However, it is also possible that these differences in effect size were due to a self-selection artifact. Specifically, significantly more vMOL than cMOL participants complied with their instructed strategy. Thus, if participants found cMOL more difficult to use than vMOL, cMOL participants may have been more motivated or have been better at remembering items in general than participants in the vMOL group. Additionally, it is notable that participants in both the vMOL and cMOL groups performed significantly better than those in the control group, even though they were only briefly instructed on how to use the MOL strategy. Finally, the specific environment used by vMOL participants did not significantly influence their recall performance. Thus, this indicates that the similarity

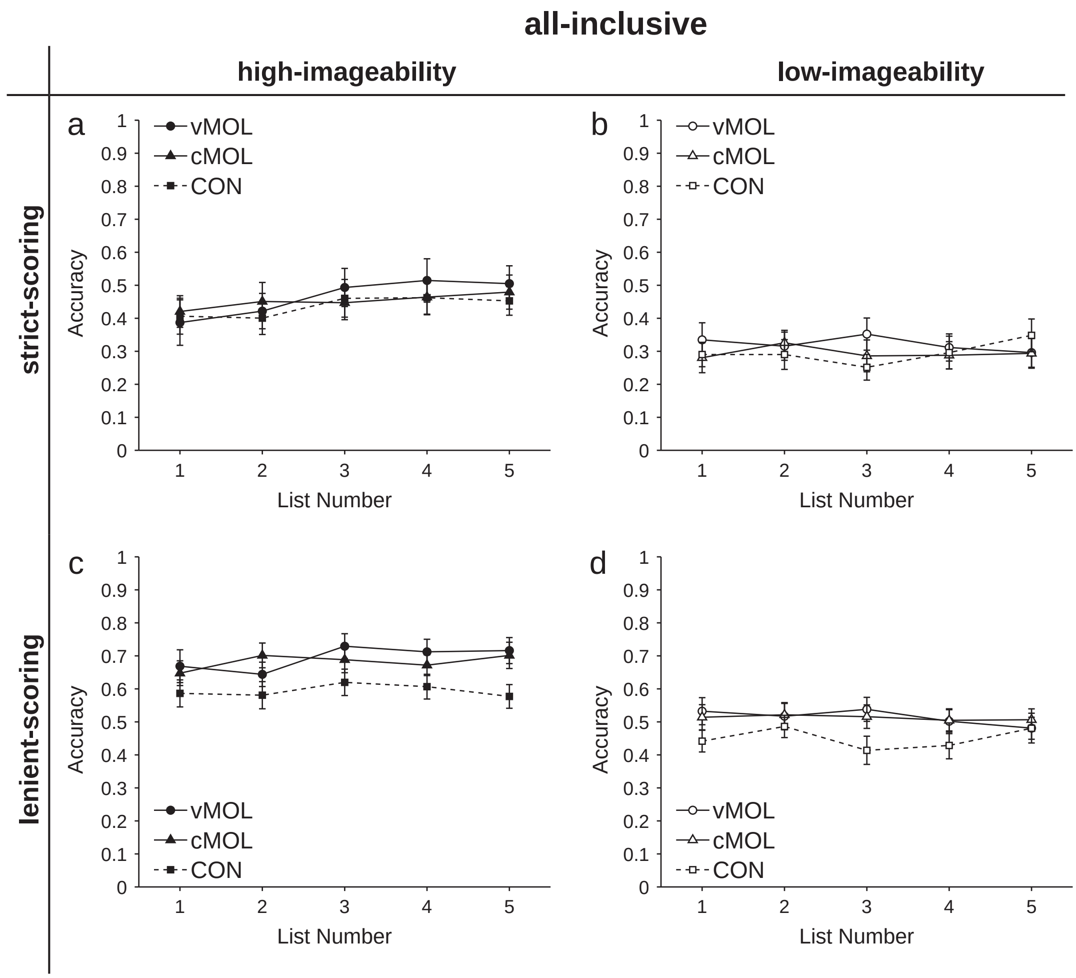

Fig. 6. Accuracy as a function of List Number for the all-inclusive analyses, separately for high- and low-imageability lists. Accuracy analyses were conducted based on both (a–b) strict-scoring and (c–d) lenient-scoring. Error bars are 95% confidence intervals, corrected for individual differences.

between the traditional and novel virtual MOL protocols were not limited to the spatial characteristics of a particular environment.

4.2. Training

One of the most significant differences between our experiment and previous MOL studies lies in how we trained participants to use the strategy. Many previous studies of the MOL have used different training instructions and methods, as well as different lengths of training prior to testing, making between-study comparisons difficult. For example, when training participants to use the MOL, Roediger (1980) instructed participants to imagine and use a familiar location through which they could walk and place images of to-be-remembered items. Roediger trained participants for two sessions, of at least 1 h each, prior to testing. He also asked participants to practice their strategies at home prior to testing. Similarly, Cornoldi and De Beni (1991) asked participants to make a list of 20 locations in their university town and then instructed them to use these locations with multiple mnemonic strategies, including the MOL, during three training seminars lasting at least an hour. In contrast to these studies, we used instructions worded closely to the traditional MOL instructions as documented by the historian Yates (1966, see Appendix). We only gave participants a maximum of 5 min to learn the virtual environment for use with the MOL. Thus, even though our participants were not trained as extensively as other studies on the MOL, we still observed a significant enhancement of memory when using the MOL compared to uninstructed strategy use.

It should be noted, however, that while our results indicate that participants can effectively use the MOL after a short period of training, the magnitude of our effect is not as large as others have found with extensively trained participants (e.g., Bower & Reitman, 1972; Brehmer et al., 2007; Brooks et al., 1993; Moé & De Beni, 2005; Roediger, 1980). Thus, while participants were using the MOL in our experiment, it is likely that they could still improve further relative to uninstructed controls if given more training, and with the current data, we cannot speak to the comparison of vMOL and cMOL for MOL-experts.

It is possible that some of the differences observed between MOL and CON groups were due to MOL participants having prior knowledge and practice with the strategy prior to taking part in our study. This is particularly plausible as all participants were recruited from an introductory psychology course where the MOL is included as part of the curriculum. However, this course topic may have been taught after participation in our study. Although there was no significant difference between groups in the proportion of participants who had prior knowledge of the MOL (see Section 3.1), accuracy in both MOL groups may have been inflated due to this prior knowledge.

4.3. Importance of compliance

When conducting research using mnemonic strategies, particularly complex strategies such as the MOL, verifying participant strategy compliance prior to conducting analyses is critical. In our experiment, many participants in both MOL groups reported failing to use their instructed

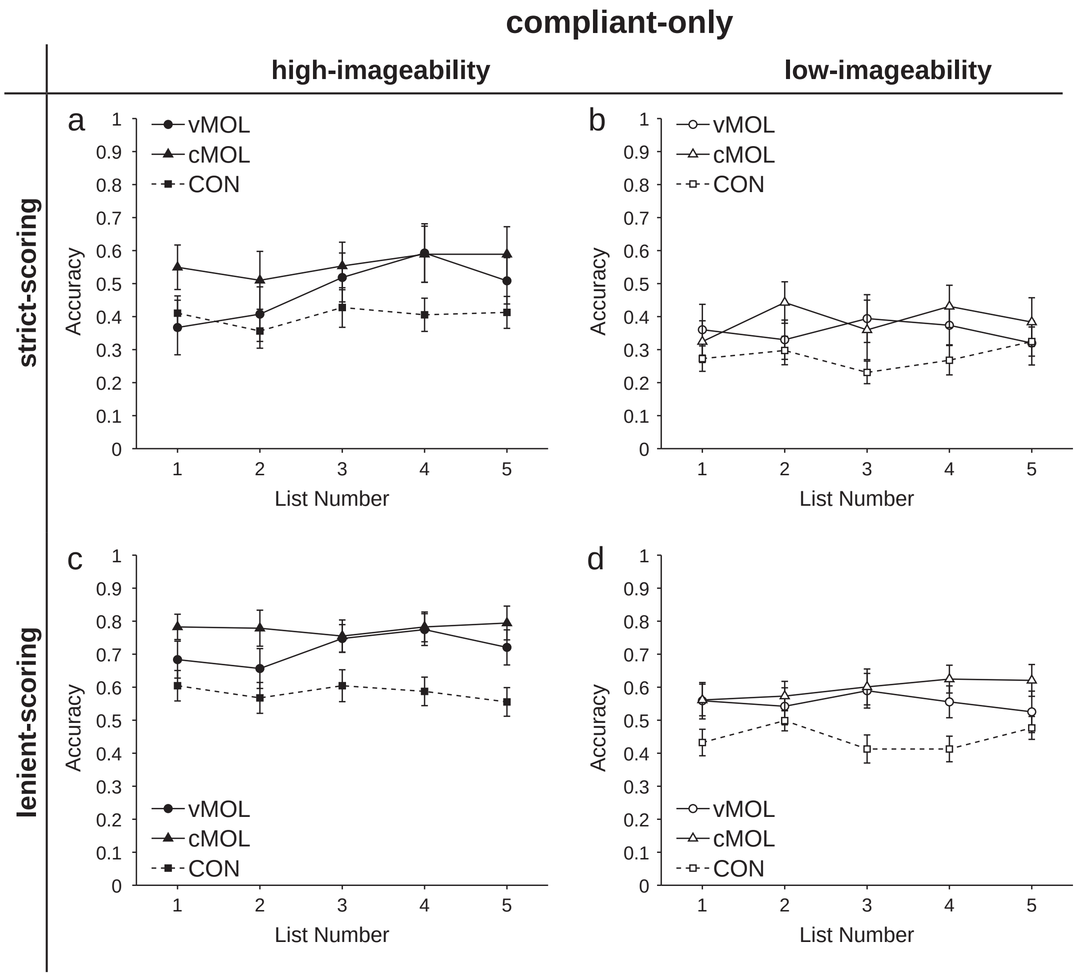

Fig. 7. Accuracy as a function of List Number for the compliant-only analyses, separately for high- and low-imageability lists. Accuracy analyses were conducted based on both (a–b) strict-scoring and (c–d) lenient-scoring. Error bars are 95% confidence intervals, corrected for individual differences.

strategy on the majority of trials. After excluding non-compliant participants, our results regarding the influence of the MOL on recall were no longer contaminated and allowed for more reliable comparisons. We suggest that future studies of mnemonic strategies should incorporate measures of strategy compliance, or possible significant findings may be masked due to non-compliant participants. While excluding non-compliant participants reduced the sample size of each group, and thus reduced the power of the observed effects, we were still able to draw meaningful conclusions from our results, and were able to observe significant effects that were otherwise obscured by the non-compliant participants (see all-inclusive analyses).

Additionally, we found that vMOL participants were significantly more likely to be compliant than cMOL participants, indicating the possibility of a self-selection artifact in our data. Specifically, if participants found cMOL more difficult to use than vMOL, cMOL participants may have been more motivated or better at remembering items in general than participants in the vMOL group. This may also indicate participants found using the virtual MOL protocol easier than the conventional MOL protocol, which may have important implications for research into memory enhancement and compensation protocols.

One limitation of our experimental design was that we were unable to evaluate the specific lists in which participants were compliant with the instructed strategy. We only obtained participants' self-reported rate of compliance at the end of the experiment. In future studies, it would be useful to have participants give a self-report of strategy compliance at the end of each list.

4.4. Serial order and MOL

We tested the hypothesis that, because of the spatial navigation component of the MOL, the MOL would be particularly specialized for remembering serially ordered information (also see Madan & Singhal, 2012a). Specifically, because a person using the MOL can "re-trace" the path they had initially taken when placing items in their imagined environment, they should have an advantage for recalling the items they placed in order (strict-scoring analyses). Contrary to our hypothesis, we found larger effect sizes for the main effect of Group when using the lenient-scoring method than the strict-scoring method for compliant-only analyses. This suggests that the MOL generally enhanced memory performance, rather than being particularly specialized for order-memory. This contrasts with Roediger (1980), where the MOL was found to especially enhance order-memory. This discrepancy between the present study and those found by Roediger place a boundary condition based on training protocol; Roediger trained participants over days, whereas we only trained participants for minutes.

Compliant-only analyses revealed that both cMOL and vMOL groups were significantly better at remembering items in order than uninstructed controls. There was no difference in serial order recall accuracy between cMOL and vMOL groups. Furthermore, the near-zero magnitude of the effect size for cMOL to vMOL comparison suggests that there really was no difference in serial order recall accuracy between MOL groups. Additionally, there were no serial position interactions observed across groups. Specifically, Figs. 4 and 5 show that for both all-inclusive and compliant-only datasets, no strategy was particularly better or worse for a given list than others.

Furthermore, we did not find any evidence to support the hypothesis that the MOL became less effective as the number of lists presented to participants was increased (see Figs. 6 and 7). This finding indicates that the MOL may not be as susceptible to proactive interference as previously thought (De Beni & Cornoldi, 1988; Massen & Vaterrodt-Plünnecke, 2006). Additionally, we also did not observe an increase in accuracy as the number of lists increased as would be expected if strong practice effects were present. Specifically, due to the MOL being a difficult to use and novel mnemonic for most participants, it did not appear that it became easier to use over time when compared with an uninstructed control. However, it is possible that there were both practice and proactive interference effects present, but occurring simultaneously. It is possible that these effects approximately offset each other, and we may have been unable to detect interactions between group and list number for this reason.

4.5. Imageability and MOL

We tested the hypothesis that, because MOL is based on visual imagery, participants using the MOL would show a significant improvement in recall of high-imageability words compared to low-imageability words when compared to uninstructed participants. In all analyses, we replicated prior findings that high-imageability words are more easily recalled than low-imageability words (Allen & Hulme, 2006; Paivio, 1971; Walker & Hulme, 1999). But surprisingly, we did not observe any interaction of group with imageability. Furthermore, we found a near-zero magnitude of effect sizes for imageability by strategy interactions across scoring methods, thus allowing us to conclude that imageability did not differentially affect recall accuracy across groups.

While we did not observe any interaction of imageability with strategy in the current study, it is possible that other word properties may still produce such an effect. Specifically, Madan and Singhal (2012b) recently found that word manipulability can influence memory performance. Following from this result, it is possible that the words representing objects that are of greater or less functional manipulability may still interact with the MOL's ability to enhance memory.

4.6. Applications and future research

One of our main goals in this paper was to determine whether we could develop a MOL protocol using virtual environments, to bring a new kind of experimental control to MOL research. Our results demonstrated that our virtual protocol, using environments created using a first-person gaming platform, substantially improved memory recall relative to our control group. Additionally, there was very little difference in memory performance found between virtual and conventional MOL protocols. Thus, this new virtual protocol could make possible future research with a greater degree of experimental control in terms of the spatial and navigational characteristics of the environment used, as well as the kind and amount of experience participants have with the environment. When using conventional MOL protocols, researchers could not control the spatial properties and features of the environments participants used; the strategy required participants to use personally familiar locations. Thus, an affluent participant who used their large, well-furnished home could potentially have an advantage over a less-affluent participant who used their sparsely furnished one-bedroom apartment. With virtual environments, researchers could control for such confounds by having all participants use the *same* environment.

The use of a virtual MOL protocol may also be of use to professional mnemonists, as the prevalence of user-friendly, virtual environment creation software is readily available to the public at low cost (i.e., most first-person perspective games now come packaged with such software). Thus, with little effort, professional mnemonists may use such software to create many diverse environments to use as the basis for the MOL, allowing them to tailor the richness and theme of each space to the list of items they wish to remember. For example, if they had to remember large lists of common household items, they could create an environment with a large and detailed kitchen, with many drawers and cabinets, for placement of these items when using the strategy. Similarly, if they had to remember large lists of automobiles, they could build a virtual garage with many unique locations to place the cars when using the strategy during encoding. Finally, if the mnemonist had to remember many lists of categorically similar items, such as one list of automobiles and another of kitchen appliances, they could recall navigating the garage environment to recall the automobiles and the kitchen environment to recall the household items.

Finally, our virtual MOL protocol may also be useful for the development of training programs for individuals with age-related memory impairments or neurological deficits. Specifically, the virtual MOL protocol can easily be incorporated into rehabilitation programs that patients can use as part of a daily memory training program, potentially attenuating age-related memory deficits or as a means to generally increase memory capacity in those who have deficits due to neurological damage. Nonetheless, it should be noted that such training programs would initially require patients to learn to use with the virtual environment, reducing the short-term benefits of such a program.

5. Conclusion

In sum, our study has expanded our knowledge of the MOL mnemonic in a number of ways. First, we demonstrated that even with extensive changes to the conventional protocol (e.g., using a briefly presented novel virtual environments as the basis for the strategy or giving people very little training in the strategy prior to testing) the effectiveness of the MOL is *not* attenuated. Secondly, our study has shown that even with very little training, participants using the MOL significantly outperform participants who are not instructed to use a particular strategy. Third, contrary to previous research (e.g., Roediger, 1980), we found that the MOL is not particularly useful for remembering items in order. Instead, the MOL seems to generally enhance memory performance for a list. Fourth, based on the compliance rates for cMOL and vMOL groups, we found evidence that our virtual MOL protocol may be more effective for memory enhancement or compensation training than the traditional MOL protocol. Fifth and finally, while our experiment did replicate work showing that high-imageability words are recalled more accurately than low-imageability words (e.g., Allen & Hulme, 2006; Paivio, 1971; Walker & Hulme, 1999), we found no evidence to support the notion that the MOL is a specialized strategy for remembering high-imageability words. Such a virtual environment procedure may provide a valuable tool for researchers wishing to conduct highly controlled investigations of the MOL.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.actpsy.2012.09.002.

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Appendix A

Method of Loci instructions

The Method of Loci has been proven to significantly increase the effectiveness of memory. Below is a description of the Method of Loci, paraphrased from The Art of Memory by Yates, the established historical text on the Method of Loci.

In this method, memory is established from places and images. If we wish to remember an object, we must first imagine that object as an image, and then place it in a location. If we wish to remember a list of objects, then we must make a path out the many locations. The easiest way would be to imagine a familiar environment and place the imagined objects inside it. Then, you can pick up the objects as you imagine navigating the environment, thereby remembering the object list in order.

[*Note: the last sentence of the instructions differed depending on the MOL group to which a participant was assigned.*]

cMOL: Use the Method of Loci for this task, using your own house as the environment.

vMOL: Use the Method of Loci for this task, using the virtual environment you just familiarized yourself with as the environment.

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