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Understanding How Working Memory Capacity and Domain-Specific Knowledge Influence Memory Performance

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Abstract

The relationship of working memory and domain knowledge to memory performance was investigated in this study. Young adults (*N* = 290) completed a demographic questionnaire and the Baseball Knowledge Test via an online platform. A subsample (*N* = 70) was selected to undergo further testing in a laboratory setting. Participants viewed two half-innings from recorded Major League Baseball games and provided verbal recollections. During one recollection, participants performed a concurrent task designed to reduce working memory resources. Testing sessions concluded with the administration of two complex working memory span tasks. Analyses indicated that domain knowledge and working memory predicted memory performance under normal and cognitive load conditions, and that these variables had an additive effect. In addition, our manipulation of working memory load impaired performance regardless of level of domain knowledge. Together, our findings suggest that domain knowledge and working memory independently influence memory performance.

Keywords
working memory, domain knowledge, expertise

Introduction

It is well established that knowledge of a given domain facilitates recall of information in that domain. For example, Spilich, Vesonder, Chiesi, and Voss (1979) found that after listening to a description of a half-inning of a fictitious baseball game, participants high in baseball knowledge recalled more game actions and other game-relevant information, but less irrelevant information, than did participants lower in baseball knowledge. Similarly, after listening to short vignettes from a game, participants high in baseball knowledge were better able to detect changes in the event descriptions on a subsequent recognition test than participants lower in baseball knowledge, especially when the changes related to the goal structure of the game (Chiesi, Spilich, & Voss, 1979; Experiment 1). Walker (1987) also found a domain-knowledge effect when participants could read as well as listen to a half-inning game description. Finally, Recht and Leslie (1988) reported the same effect when participants read silently the half-inning description.

Although the positive effect of domain-specific knowledge on memory performance is well-established, it is unclear whether and how other factors moderate this effect. This study focuses on working memory capacity. Hambrick and Oswald (2005) outlined three competing hypotheses concerning the interplay between domain knowledge and working memory capacity: the *independent influences hypothesis*, the *compensation hypothesis*, and the *rich-get-*

richer hypothesis. The independent influences hypothesis simply assumes there is no interaction between working memory capacity and domain knowledge — in other words, that the two factors have main effects on performance. The compensation hypothesis claims that with the acquisition of knowledge in a particular domain comes the reduced demand on working memory resources, and thus that the influence of working memory capacity on domain-relevant performance decreases as knowledge increases (this hypothesis has also been referred to as the *circumvention-of-limits hypothesis*). Finally, the rich-get-richer hypothesis proposes that high working memory capacity improves the ability to utilize knowledge in a given domain, and thus that there is an interaction between the two factors such that high working memory capacity amplifies the effect of domain knowledge on performance.

Hambrick and Oswald (2005) found support for the independent influences hypothesis in a study in which participants performed a memory task that involved tracking the movement of baseball players (the domain-relevant task) and spaceships in an isomorphic task (the non-domain-relevant task). More specifically, working memory capacity and domain knowledge had additive effects on memory performance in both the baseball and spaceship versions of the task. Meinz et al. (2012) also found support for the independent influences hypothesis in a study of Texas Hold'Em players; that is, domain knowledge and working memory capacity had additive effects on performance in poker skill tasks. Further support for the independent influences hypothesis was found in a study of pianist's sight-reading ability (Meinz & Hambrick, 2010). Both deliberate practice and working memory capacity positively predicted performance on the sight-reading task, although the interaction between the two was non-significant.

There is also some support for the compensation hypothesis. Hambrick et al. (2012) found a statistical interaction between visuospatial ability and domain knowledge in a geological problem-solving task, with geologists' visuospatial ability being predictive of bedrock mapping skill at low but not high levels of domain knowledge. Similarly, Sohn and Doane (2003) found that pilots relied less on working memory at higher levels of aviation knowledge, and Gonzalez and Wimisberg (2007) found that individuals with superior situational awareness could circumvent working memory limitations.

Still other studies have suggested that high working memory capacity facilitated an individual's ability to retrieve and use domain knowledge, supporting the rich-get-richer hypothesis. Hambrick and Engle (2002) reported that participants' memory for the events of a fictional baseball radio broadcast was predicted by working memory capacity, but that domain knowledge amplified this effect. Specifically, high working memory capacity disproportionately benefited participant performance at high levels of domain knowledge, consistent with the rich-get richer hypothesis. Leeser (2007) found a similar interaction between working memory capacity and domain knowledge for individuals who speak Spanish as a second language. Those with high working memory capacity performed better at text recall than those with low working memory capacity at the same level of domain knowledge, although this difference was most pronounced at high levels of domain knowledge.

Thus, the independent influence, compensation, and rich-get-richer hypotheses have all received some support across different domains and tasks. Given this state of affairs, one goal of the present experiment was to reexamine the role of baseball knowledge and working memory capacity in a task requiring the recollection of a half-inning of a baseball game. Hambrick and Engle (2002) found that high working memory capacity most benefits those with a high degree of baseball knowledge. Recht and Leslie (1988) found that reading ability boosted recall of baseball game events as did domain-specific knowledge, but the two factors did not interact. Also, Walker (1987) found no main effect of aptitude as assessed by the Army test for general/technical ability on recall but only a main effect of baseball knowledge. Further aptitude and baseball knowledge did not interact. Given that reading ability and aptitude test scores are related but not identical to measures of working memory capacity, these findings do not necessarily contradict those reported by Hambrick and Engle (2002), but they do raise concerns. Our first goal, therefore, was to reexamine the evidence favoring the rich-get-richer hypothesis in a conceptual replication of Hambrick and Engle (2002).

A second goal here was to experimentally manipulate the availability of working memory resources in a baseball game recall task. Past studies have used a correlational design to investigate the influences of working memory capacity and baseball knowledge in this paradigm. In this study, we experimentally manipulated demand on working memory resources through use of a concurrent (or secondary) task. Our specific question of interest was whether this manipulation affected memory performance the same or differently for those with a low versus high level of domain knowledge. Using this approach, we evaluated the independence, compensation, and rich-get-richer hypotheses.

A third goal was to extend past studies in which participants listened to or read a description of a half-inning of a fictitious game to watching a video recording of an actual major league game. We anticipated that both domain knowledge and working memory capacity would contribute to better recollection after watching a game in real time without a detailed play-by- play account. Although radio broadcasters often provide a detailed description of the game actions, television broadcasters can allow the viewer to see the actions for themselves. Thus, the materials used in the present experiment are different from Hambrick and Engle's (2002) and all prior baseball memory studies.

A final goal of this study was to extend our assessment of baseball knowledge beyond the Baseball Knowledge Test developed by Chiesi, Spilich, and Voss (1979) and used by other researchers. This test measured declarative knowledge about baseball. However, procedural knowledge gained from actually playing the game is also of interest. For example, a professional quarterback and a color commentator for a football broadcasting network (with no playing history) should both know plenty about the sport, although their experience of the game is likely quite different. We examined whether the number of years playing a sport aided in recalling the events of the game. Experience playing the game of baseball likely provides non-declarative or procedural "how" knowledge that may potentially add to declarative "what" knowledge. One may be an expert observer of games who scores highly on a test of declarative knowledge without any experience in actually playing the game. Thus, along with having participants complete the Baseball Knowledge Test as an assessment of declarative knowledge, we asked them to report how much experience they had in actually playing the game of baseball.

Findings by Williams and Davids (1995) suggest that the kind of experience may be important to assess. Soccer players with high- and low-skill, and physically disabled "experienced spectators" were recruited for the study. Participants were asked to view clips from soccer matches, and were assessed on their predictive ability, recollection, and recognition of events. The authors found that high-skill and low-skill players were more accurate in their predictions of future ball locations relative to experienced spectators. Importantly, high-skill players were also quicker in their predictions relative to both groups. Furthermore, high-skill players were more precise than low-skill players, and low-skill players more precise than experienced spectators in the recollection of player positions during clips of structured (e.g., offensive attack), but not unstructured events (e.g., injury stoppage). Indeed, there were no group differences when unstructured events were shown. Finally, high-skill players were more accurate and quicker in their recognition of screenshots from clips played 30-minutes prior relative to low-skill players and experienced spectators. Williams and Davids concluded that the procedural knowledge of high skill players enriched and elaborated the declarative knowledge base.

Rationale

To reiterate, the primary aims of this study were to gain a better understanding of the relative contributions of domain knowledge and working memory capacity to memory performance. Based on previous research, we hypothesized that high levels of both baseball knowledge and working memory capacity would be associated with superior memory performance. Our major research question was whether working memory capacity interacted with domain knowledge. Depending on the direction of the interaction, such an outcome would support the compensation hypothesis or the rich-get-richer hypothesis. If, however, working memory and domain knowledge had an additive effect on performance, this would support the independent influences hypothesis.

We further hypothesized that the cognitive load condition would reduce participants' memory performance. Again, our interest was whether this manipulation of the availability of working memory resources would have an independent or interactive effect with domain-specific knowledge. Finally, we explored whether the Baseball Knowledge Test, reflecting depth of semantic memory, differed in its relation to memory performance from a measure of non-declarative or procedural memory, namely, the number of years of playing baseball.

Method

Materials

Demographics Questionnaire and Baseball Knowledge Test. A demographics questionnaire and the Baseball Knowledge Test were administered to participants during the first part of the study using an online survey platform. The questionnaire came first and asked the participant's age, sex, primary language, history of traumatic brain injury, favorite professional baseball team (if any), and prior baseball or softball coaching history. As further background information regarding the sample, participants rated on a 5-point ordinal scale the number of hours spent watching baseball or softball a week (1 = 0 hours; 5 = 10+ hours), number of hours spent listening to baseball or softball a week (1 = 0 hours; 5 = 10+ hours), and number of baseball or softball games attended a year (1 = 0 games; 5 = 7+ games). Finally, participants estimated the number of years they had spent playing baseball or softball.

The Baseball Knowledge Test developed by Spilich et al. (1979) consists of 45 questions regarding the rules, terminology, and tactical decisions of a baseball game. The questions were multiple-choice, fill-in-the-blank, or free-response in structure. Examples of questions included: "What does ERA stand for?", "When is a batter allowed to run to first base even though he struck out?", and "The distance between any two bases is: ________." In addition, one question was included to assess whether the participants were attentive and genuinely attempted to answer the questions ("Who is the current president of the United States of America?"; A: Barack Obama). The two key measures of domain knowledge were the score on the Baseball Knowledge Test and the number of years spent playing baseball or softball. The former provided an index of semantic knowledge about the game, whereas the latter indexed procedural knowledge.

Major League Baseball (MLB) Greatest Games DVD. Two half-inning video clips from the Major League Baseball (MLB) Greatest Games DVD Box Set were presented to participants on a 20- x 13-inch computer monitor. The following half-innings were presented to participants in a counterbalanced order: The bottom of the second inning of game seven of the 1991 World Series (Minnesota Twins v. Atlanta Braves), and the top of the eighth inning in game six of the 1993 World Series (Toronto Blue Jays v. Philadelphia Phillies). The video clips were selected because both had similar run times, were played in similar eras, involved "mid-market clubs," and contained the same number of significant events. Major League Baseball Advanced Media (MLBAM) provided consent permitting the use of the video clips for the purposes of this study.

Digit Span. In the cognitive load condition, six-digit strings were presented during one recall portion of the study via E-Prime Professional 2.0.10 (see Figure 1). Participants were presented with the initial string (e.g. "986237") for 5 seconds. Following a 15 second delay in which the screen displayed a fixation cross, participants were then presented with another six-digit string in red font. On this screen, participants were to confirm ("Z" key) or disconfirm ("/" key) that this second string matched the first in a timed recognition task. The total number of trials was contingent on the length of the participant's description of the half-inning.

Shortened Version of the Operation Span (OSpan). The operation span (OSpan) required participants to remember letters while alternatingly confirming or disconfirming the solution to a presented math equation (Turner & Engle, 1989; see Figure 1). The OSpan consisted of three practice blocks (pure letter, pure number, and mixed block) and one experimental block. The practice blocks familiarized the participants with the letter memory task, algebraic task, and the interleaved trials of both. One experimental block from the shortened version of the OSpan, developed by Foster and colleagues (2014), was used and administered electronically via E-Prime 2.0.10.

Shortened Version of the Symmetry Span. The symmetry span (SymSpan) required participants to remember the location of red-shaded boxes within a larger 4 x 4 grid while alternatingly determining whether a darkly-shaded figure embedded in an 8 x 8 grid was symmetrical along its vertical axis (Shah & Miyake, 1996; see Figure 1). The SymSpan consisted of three practice blocks (pure block, pure symmetry, and mixed block) and one experimental block. The practice blocks familiarized the participants with the box memory task, symmetry task, and the interleaved trials of both. One experimental block from the shortened version of the SymSpan, developed by Foster and colleagues (2014), was utilized and administered to participants via E-Prime 2.0.10.

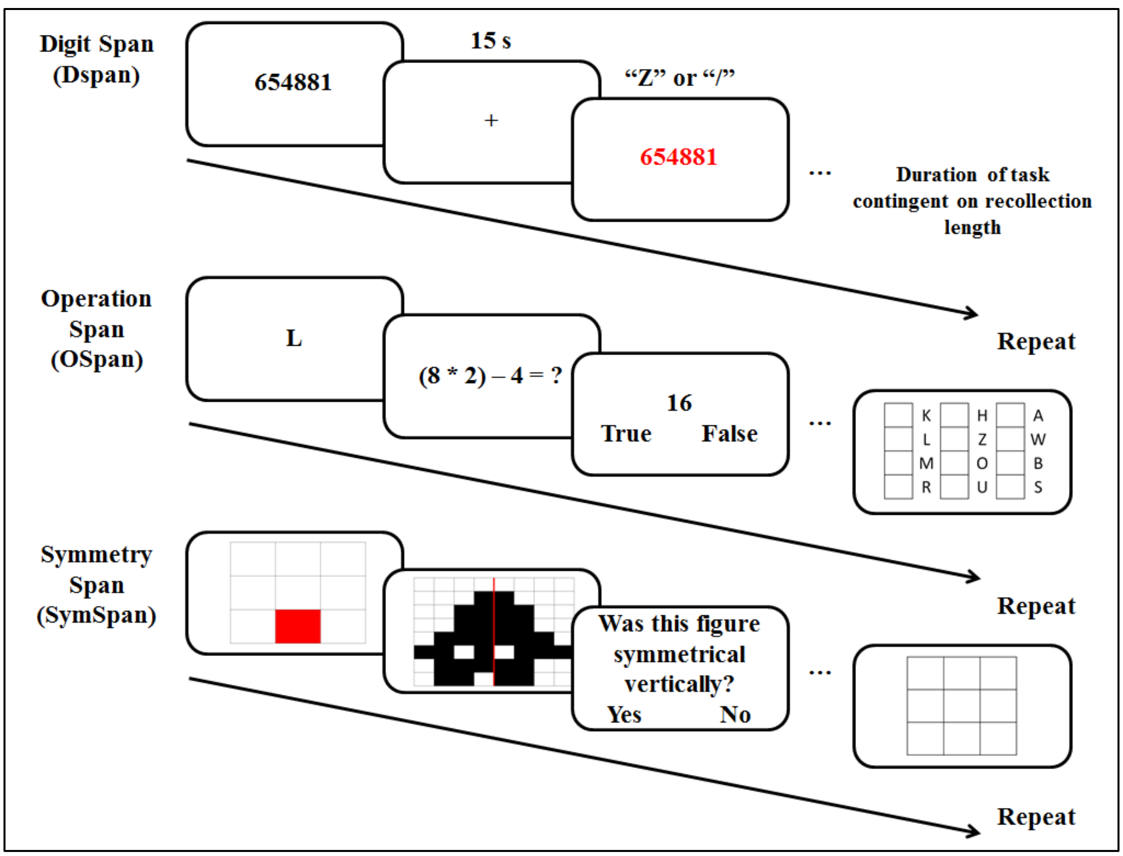

Figure 1. E-Prime Computer Tasks

Procedure

The participants in Part 1 of the study were undergraduate students (*N* = 290) from a medium-sized university in the midwestern United States. First, participants were asked to complete the demographics questionnaire assessing personal and baseball-related histories. Participants then were asked to complete the Baseball Knowledge Test. The research session concluded by asking whether the participant sought out external aids to help answer the questions (e.g. roommate, internet, etc.), and whether they would be willing to come into the laboratory to undergo further testing.

After this preliminary phase of the study, participants who consented to further testing (*N* = 70) were individually tested in a laboratory. Following consent, participants were directed to a 20- x 13-inch computer monitor and told that they were to watch a video clip of a half-inning of a baseball game. The participant was instructed to remember in as much detail the events and context of the inning, with the objective to recall this information at a later point in time. Once the participant understood the directions, the research assistant started the first video. The video clips were presented in a counterbalanced order.

Following the conclusion of the half-inning, the research assistant started the audio recording software and the E-Prime program for either the control or cognitive load condition, which was also completed in a counterbalanced order. Participants were asked to read detailed instructions regarding the recollection task on the screen, directing any questions that they may have to the research assistant. The instructions stated that they were to recall the events and context of the inning in as much detail as possible into the microphone, and that the recollection was not timed. Additionally, for the cognitive load condition, the digit span task was explained, including the appropriate button presses. Participants did not attempt practice trials of the digit span task to ensure that the amount of time between the conclusion of the video and the start of the verbal recollection remained consistent across conditions, reducing the likelihood of decay effects.

Following the viewing and recollection of both half-innings, participants were then asked to complete one block of the OSpan and SymSpan. The order in which the participants were to complete the complex span tasks was counterbalanced. Then, after the completion of the complex span tasks, participants were debriefed and thanked for their participation.

Following data collection, the verbal recollections provided by the participants were transcribed and then scored using a rubric modified from Spilich et al. (1979). This rubric was used to tally the quantity of essential information conveyed in the participant's recollection (See Appendix A and B).. Last, the word count, number of filler words, and nonfluencies were analyzed using the computer program, Linguistic Inquiry and Word Count (LIWC; Pennebaker, Booth, & Francis, 2007).

Participants

Young adults (*N* = 290, 203 female, M_{age} = 18.97, age range = 17-25) were recruited for Part 1 of the study via SLU's psychology department's online participant pool. Part 2 consisted of young adults (*N* = 70, 37 female, M_{age} = 18.77, age range = 18 – 22) who were enrolled in Part 1 of the study and returned to the laboratory for additional testing. These 70 participants reported almost no experience in coaching baseball (*M* = .04, *SD* = .27). On the 5-point ordinal scale measuring the number of hours spent watching or listening to games, the most frequent response was 2, corresponding to 1-3 hours per week. In addition, the modal response for the number of games attended was 3, corresponding to 3-4 games per year.

Power Analysis

A post-hoc power analysis indicated that a sample size of 77 would be sufficient to detect a medium-size effect of a predictor variable on memory performance in a multiple regression analysis ($1 - \beta > .80$, Cohen's $f^2 = .15$).

Results

Although 70 participants were enrolled in Part 2, data were missing for some participants due to an E-Prime program malfunction, reducing the number of usable cases for some analyses. Little's Missing Completely at Random test was used to determine if missing cases for the OSpan, SymSpan, Digit Span, and recollection tallies were missing completely at random. The resulting chi-square was statistically non-significant, indicating that there was no systematic bias in the missing data (χ^2 (16, N = 70) = 14.70, p = .55).

Overview

Descriptive statistics for the Baseball Knowledge Test, years of baseball/softball played, working memory capacity and digit span are displayed in Table 1. Correlations were computed to investigate relationships between domain knowledge, working memory capacity, digit span, and outcome measures (see Table 2). There were several noteworthy findings. First, number of years played correlated positively with the Baseball Knowledge Test score ($r(69) = .52$, $p < .001$, 95% CI [.35, .67]), indicating that procedural and declarative knowledge of baseball are correlated. Second, a significant relationship between OSpan and SymSpan scores was also found ($r(67) = .31$, $p < .05$, 95% CI [.09, .53]). Third, a significant negative relationship was found between Baseball Knowledge Test and OSpan scores ($r(67) = -.37$, $p < .01$, 95% CI [-.57, -.18]).

This finding was unexpected and difficult to explain. Fourth, Years Played correlated with recollection tallies in the control ($r(68) = .34$, $p < .01$, 95% CI [.02, .44]) and cognitive load conditions ($r(65) = .29$, $p < .05$, 95% CI [.02, .50]); SymSpan also correlated with tallies in the control ($r(67) = .32$, $p < .01$, 95% CI [.07, .57]) and cognitive load ($r(64) = .30$, $p < .05$, 95% CI [.06, .54]) conditions. Finally, there was a strong positive correlation between tallies in the control and cognitive load conditions ($r(65) = .82$, $p < .001$, 95% CI [.72, .92]).

Table 1. Descriptive Statistics of Participants Enrolled in Part 1 and 2

	Part 1				Part 2			
Variable	*Mean* (*SD*)	Range	*Z*-Skew	*Z*-Kurt	*Mean* (*SD*)	Range	*Z*-Skew	*Z*-Kurt
BKT	15.77 (11.06)	0 – 42	3.63	-3.02	16.54 (10.68)	0 – 36.5	0.51	-2.24
YrsPlayed	3.64 (4.23)	0 – 22	8.80	3.95	3.67 (4.13)	0 – 15	3.97	0.64
OSpan					18.40 (4.92)	5 – 25	-2.61	-0.05
SymSpan					9.45 (2.99)	0 – 14	-1.65	0.31
DSpanProp					.60 (.30)	0 – 1	-1.76	-0.69

Note. Abbreviations: BKT = Baseball Knowledge Test Score; YrsPlayed = Number of Years Playing Baseball/Softball; OSpan = Operation Span; SymSpan = Symmetry Span; DSpanProp = Proportion of Digit Span Strings Correctly Remembered.

Table 2. Correlation Matrix on Independent Variables

Variable	1	2	3	4	5	6	7
(1) BKT	–						
(2) YrsPlayed	.52**	–					
(3) OSpan	-.37**	.01	–				
(4) SymSpan	-.09	.13	.31*	–			
(5) DSpanProp	-.03	-.03	.04	.07	–		
(6) CTally	.13	.34**	.02	.32**	.13	–	
(7) DSTally	.11	.29*	.05	.30*	.18	.82***	–

Note. BKT = Baseball Knowledge Test Score; YrsPlayed = Number of Years Playing Baseball/Softball; OSpan = Operation Span; SymSpan = Symmetry Span; DSpanProp = Proportion of Digit Span Strings Correctly Remembered; CTally = Control Recollection Tally Score; DSTally = Digit Span Recollection Tally Score.
* p < .05; ** p < .01, *** p < .001

We performed a paired samples *t*-test to compare recollection tally scores across condition. A significant difference was detected, $t(65) = 2.97$, $p < .01$, $d = .22$; participants scored higher in the control condition ($M = 11.18$, $SD = 5.23$) than in the cognitive load condition ($M = 10.05$, $SD = 4.98$). This finding indicates that the manipulation of working memory load reduced participants' ability to recall the events and context of the half-innings. Another indicator that the concurrent digit span task affected performance came from the LIWC analyses. As anticipated, nonfluency frequency was higher in the cognitive load condition ($M = 4.75$, $SD = 3.48$) than in the control condition ($M = 3.79$, $SD = 3.05$), $t(65) = 2.90$, $p < .01$, $d = .29$.. The effect of condition on both word count and filler word frequency was non-significant.

Regression Analyses

Composite scores were created for use in the regression analyses described next. The domain knowledge composite score was created by averaging *z*-scores for the baseball knowledge test and years played; the working memory capacity composite score was created by averaging *z*-scores for SymSpan and OSpan.

Control condition. A hierarchical regression analysis was conducted on control condition recollection tally counts (see Table 3). The results yielded a significant model for Step 1 when domain knowledge ($B = 1.82$, 95% CI [.37, 3.26], Cohen's $f^2 = .10$) was the only predictor ($R^2 = .09$, $F(1,66) = 6.31$, $p < .05$). The inclusion of working memory capacity in Step 2 resulted in a statistically significant increment in variance explained ($R^2 = .14$, $\Delta F(1,65) = 4.15$, $p < .05$). Inspection of the beta coefficients indicated that both domain knowledge ($B = 2.03$, 95% CI [.61, 3.45], Cohen's $f^2 = .10$) and working memory capacity ($B = 1.57$, 95% CI [.03, 3.11], Cohen's $f^2 = .06$) were significant positive predictors of tallies. Finally, in Step 3, the domain knowledge x working memory capacity interaction was non-significant ($B = .26$, 95% CI [-1.68, 2.21], Cohen's $f^2 = .00$; $R^2 = .14$, $\Delta F(1,64) = .07$, $p = .79$).

Cognitive load condition. A hierarchical regression analysis was conducted on cognitive load condition tally counts (see Table 3). The results indicated a statistically significant model for Step 1 when domain knowledge ($B = 1.60$, 95% CI [.17, 3.03], Cohen's $f^2 = .08$) was the only predictor ($R^2 = .07$, $F(1,63) = 5.02$, $p < .05$). The inclusion of working memory capacity in Step 2 resulted in a statistically significant increment in variance explained ($R^2 = .14$, $\Delta F(1,62) = 4.44$, p < .05). Inspection of the beta coefficients indicated that both domain knowledge ($B = 1.69$, 95% CI [.30, 3.09], Cohen's $f^2 = .08$) and working memory capacity ($B = 1.68$, 95% CI [.09, 3.27], Cohen's $f^2 = .08$) were significant predictors of tallies. Finally, in Step 3, the domain knowledge x working memory capacity interaction was non-significant ($B = .78$, 95% CI [-1.29, 2.88], Cohen's $f^2 = .00$; $R^2 = .14$, $\Delta F(1,61) = .58$, $p = .45$).

Table 3. Results of Hierarchical Linear Regressions Predicting Recall

Predictor Variables	*B*	*sr*	*R*	R^2	ΔR^2	*F*	ΔF
Control Tallies							
Step 1			.30	.09		6.31*	
DK	1.82*	.30					
Step 2			.38	.14	.06	5.38**	4.15*
DK	2.03**	.33					
WMC	1.57*	.23					
Step 3			.38	.14	.00	3.56*	0.07
DK	2.01**	.32					
WMC	1.56*	.23					
DKxWMC	.26	.03					
Cognitive Load Tallies							
Step 1			.27	.07		5.02*	
DK	1.60*	.27					
Step 2			.37	.14	.06	4.87*	4.44*
DK	1.69*	.29					
WMC	1.68*	.25					
Step 3			.38	.14	.01	3.42*	0.58
DK	1.63*	.27					
WMC	1.71*	.25					
DKxWMC	0.78	.09					

Note. DK = Domain Knowledge Score; WMC = Working Memory Capacity.
* p < .05; ** p < .01, *** p < .001

Cognitive Load. The paired samples *t*-test reported above indicated that recollection performance was worse in the cognitive load condition than in the control condition, as expected. What remained unclear from this analysis was whether the cognitive load manipulation affected participants equally across levels of domain knowledge. Therefore, we conducted mixed effects general linear models using the lme4 package[1] in R (Bates, Maechler, Bolker, & Walker, 2014; R Core Team, 2017), while peudo-R^2 was calculated using the MuMIn package (Barton, 2017). We examined the composite score reflecting domain knowledge.

Variables were entered in the same fashion as in the hierarchical linear regressions reported above. To begin, only participant code was entered into the “null model” as a random effect. Then, domain knowledge was the next predictor variable entered into the model in Step 1, followed by Condition (0 = Control, 1 = Cognitive Load) in Step 2, and finally a domain knowledge x condition interaction term in Step 3. This allowed for us to determine whether the cognitive load manipulation affected performance independently of domain-specific knowledge.

First, the addition of domain knowledge (B = 1.54, 95% CI [.27, 2.81], Cohen’s f^2 = .08) improved model fit beyond that of the null model (R^2 = .07, χ^2 (4, N = 69) = 5.50, p < .05), further supporting the systematic relationship of domain knowledge with recollection scores. Second, the addition of Condition (B = -1.12, 95% CI [-1.86, -.38], Cohen’s f^2 = .01) improved model fit (R^2 = .08, $\Delta\chi^2$ (5, N = 69) = 8.33, p < .01) in Step 2. This again indicates that participants performed worse in the cognitive load condition than in the control condition. Third, the interaction term (B = -.17, 95% CI [-.69, 1.03], Cohen’s f^2 = .00) entered in Step 3 failed to significantly improve model fit (R^2 = .08, $\Delta\chi^2$ (6, N = 69) = .16, p = .69). Thus, the cognitive load manipulation had an equally detrimental effect on recollection performance across levels of domain knowledge (see Figure 2).

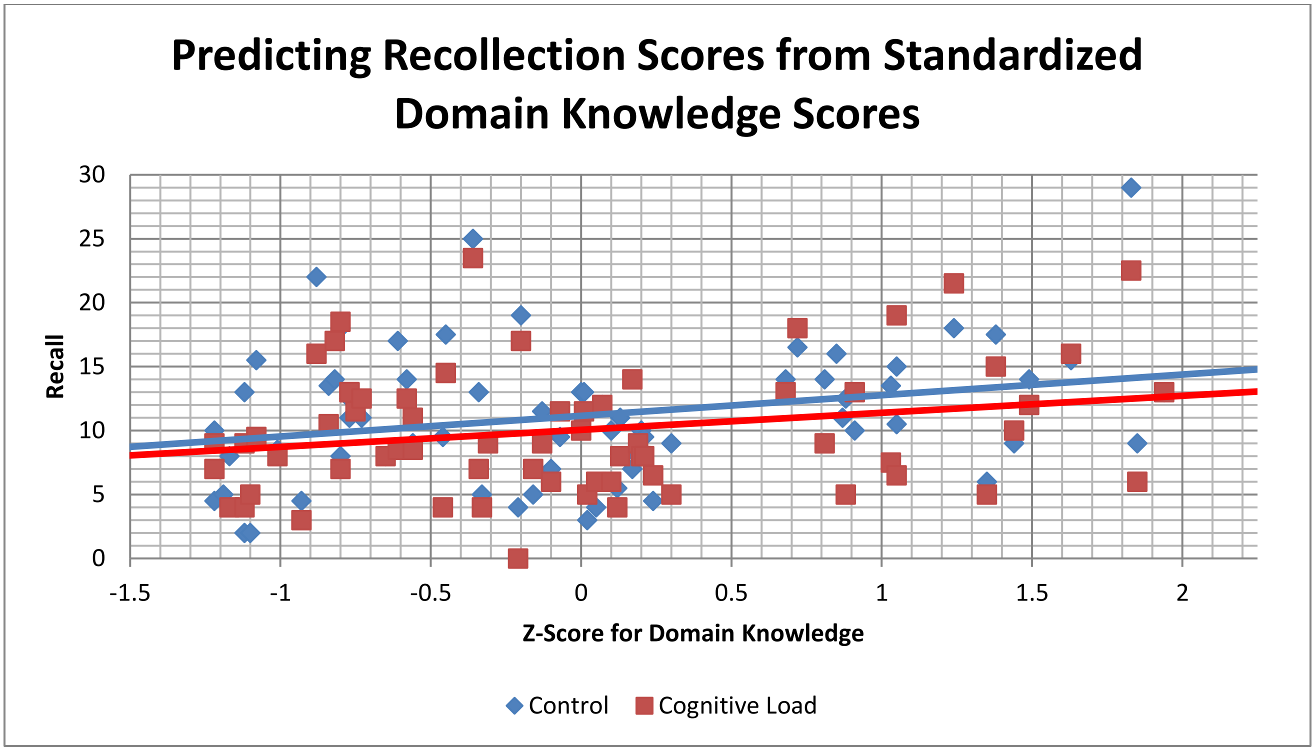

Figure 2. Predicting Recollection Performance from Standardized Domain Knowledge Scores

Discussion

The study found that domain knowledge positively predicted participants' recall the events and context of a half-inning of a baseball game. This finding confirms and extends findings from previous research showing the importance of domain-specific knowledge for recalling the actions of a baseball game (Hambrick & Engle, 2002; Recht & Leslie, 1988; Spilich et al., 1979; Walker, 1987). We assessed both semantic (Baseball Knowledge Test) and procedural knowledge (years played), and we created a composite measure of domain knowledge based on these variables. Further, as measured by complex span tasks, working memory capacity added to the prediction of recall performance, above and beyond domain knowledge. Finally, a concurrent task that disrupted the use of working memory during recall had a negative impact on recall, and this effect did not differ as a function of domain knowledge.

The study examined the three models concerning the interplay between domain knowledge and working memory capacity outlined by Hambrick and Oswald (2005). The compensation hypothesis would have been supported by the finding of a smaller effect of working memory capacity on recall at higher versus lower levels of domain knowledge. The rich-get-richer hypothesis would have been supported by the finding of a larger effect of domain knowledge on recall at higher versus lower levels of working memory capacity. Finally, the independent influences hypothesis would have been supported by the findings of additive effects of domain knowledge and working memory capacity on recall. The results supported the independent influences hypothesis: Effects of domain knowledge and working memory capacity on recall were additive. The interaction of between these factors was non-significant.

Moreover, our experimental manipulation of cognitive load during recall provided further support for the independent influences hypothesis. The size of the disruptive effect on recall performance of holding a six-digit load in working memory was not influenced by level of domain knowledge. We believe that our study is the first in this literature to manipulate the degree to which working memory could be used to recall the events of the game as well as assessing individual differences in working memory capacity. Past studies that have assessed individual differences in working memory capacity are informative, but correlational in nature. Our results with the cognitive load manipulation allow the conclusion that reducing the availability of working memory capacity during recall impairs performance and does so independently from variations in domain-specific knowledge.

Relationship of Working Memory and Domain-Specific Knowledge

Our results are thus consistent with several past studies that have supported the independent influences hypothesis. Hambrick and Oswald (2005) found that participants' performance on a memory task involving the movement of spaceships or baseball players in an isomorphic task were influenced by domain knowledge and working memory ability, although these factors had an additive effect with one another. Similarly, Meinz et al. (2012) found that domain knowledge and working memory ability had independent effects on Texas Hold'Em players' performance. Lastly, Hambrick and Meinz (2010) found that domain knowledge and working memory ability independently contributed to pianists' performance on a sight-reading task.

Even so, we are not convinced that the independent influences model provides a general lawful account of how working memory and domain-specific knowledge are related to memory performance. As outlined in the introduction, other studies using different tasks and investigating different domains of knowledge have supported both the rich-get-richer and the compensation models as well. How can these mixed results be understood? Jenkins (1979) proposed nearly 40 years ago that memory performance reflects interactions among subjects (e.g., individual differences in working memory ability or in expertise), events (i.e., the specific kinds of materials presented in the experiment), encoding (e.g., the orienting task required by instructions), and retrieval (e.g., free recall versus recognition). The findings from memory experiments are highly context-sensitive according to Jenkins' tetrahedral model of memory experiments. Roediger (2008) updated this contextual point of view with numerous examples from the memory literature. Rather than looking for a general law, the task for researchers is to document how and why results vary across subjects, events, encoding, and retrieval conditions.

We would suggest that the literature on memory for events from a baseball game provides another case in point. When participants encode the events of the game by listening to a play-by-play description of a fictitious game, domain knowledge as measured by the Baseball Knowledge Test then interacted with working memory capacity in the direction predicted by the rich-get richer model (Hambrick and Engle, 2002). That is, participants with high levels of working memory capacity benefited more from baseball knowledge than did participants with lower levels of working memory capacity. To develop a model of the game actions that benefits recall, both domain-specific knowledge and a high working memory capacity may be necessary when the materials are entirely an audio play by play account of the game rather than a visual depiction of the events with an accompanying audio commentary. By contrast, for a televised game with commentary from the announcers, working memory capacity and domain-knowledge appear to operate independently of each other. The specific nature of the materials used to portray the game events seems to matter.

As another example, our sample of college students and the three age ranges (18-39, 40-59, and 60+) studied by Hambrick and Engle (2002) varied in their experience with the game of baseball. However, even the high-knowledge participants in these studies were probably not true experts in the sense of a Grand Master chess player or an elite world-class athlete. It would be of interest in future research to test professional baseball players using our video materials or the play-by-play audio materials employed by Hambrick and Engle (2002). The depth of semantic and procedural knowledge of major league players, with scores on the

Baseball Knowledge Test at ceiling and more than a decade of playing experience, would likely be markedly greater than certainly the college students that we studied here and possibly even the most experienced adults studied by Hambrick and Engle. We suspect that the professional players' extensive knowledge of the game would compensate for those with a low working memory capacity. For true experts in a domain, the compensation model might best account for performance. Consistent with this expectation, it is notable that the studies providing support for the compensation model examined practicing geologists (Hambrick et al., 2012) and flight instructors (Sohn & Doane, 2003) as their high-knowledge participants.

Thus, the specific conditions we studied here supported the independent influences model, but it is probably unwise to expect this to be a model that applies in general across most, if not all, sets of experimental designs and procedures. Rather, per Jenkins (1979) and Roediger (2008), a key goal for researchers ought to be unpacking how various contextual factors lead to support for the compensation and the rich-get-richer models of how working memory capacity and domain knowledge interact instead of exerting independent influences.

Limitations

Our study has three notable limitations. First, the distribution of scores on the Baseball Knowledge Test and Years Played was positively skewed, with relatively few individuals receiving a high score or having played many years of baseball or softball. It is certainly the case that our participants were not experts in the game of baseball in the sense that professional major leaguers are. Compared with the samples used in past studies (e.g., Spilich et al., 1979; Walker, 1987) our participants generally had a relatively low degree of knowledge about baseball. For example, the overall mean Baseball Knowledge Test score reported by Spilich et al. (1979) was 30.5 on a 45-point scale whereas our overall mean was 16.5. Even so, our scores ranged from 0 to 36.5 suggesting that our regression analysis did not suffer from a restriction of range problem. To our knowledge, there were no other cited studies with which to compare baseball or softball playing histories. With this in consideration, even with our sample, we found a reliable contribution of domain-specific knowledge to the recall of game events. Another limitation was that we could not prevent participants from cheating on the Baseball Knowledge Test. However, participants were asked explicitly to indicate whether they used such resources as a book, the internet, or a roommate, and participants who said they did were excluded from analyses. In addition, our sample scored lower on the Baseball Knowledge Test than samples in previous research, suggesting that cheating was not common. Finally, our sample was somewhat small to detect a small interaction effect.

Conclusions

The present study of domain knowledge and working memory capacity appears to be the first of its kind in that we examined the influence of working memory constraints on all participants, regardless of preexisting working memory and domain knowledge abilities by experimentally manipulating cognitive load during recall. This study also employed a naturalistic medium through which participants could encode information, and various dimensions of spoken language were utilized as potential sensitive dependent variables to indicate differences between performance when under a cognitive load. Importantly, our findings lend support to the independent influences hypothesis.

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Footnote

1. This package tests changes in model fit using chi-square as opposed to *F*-tests, thus explaining why the reported statistics differ in the subsequent analyses.

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

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Appendix A. Baseball Recollection Rubric (1991)

Context

General

- Atlanta Braves
- Team pitching
- Inning
- Score
- Minnesota Twins
- Team batting
- Weather conditions

Specific

Relevant

- Batting averages
  - Kent Hrbek (.130)
  - Chili Davis (.214)
  - Brian Harper (.353)
  - Shane Mack (.310)
  - Mike Pagliarulo (.279)
- Hits
  - Kent Hrbek (0-13)
  - Shane Mack (2-19)
  - Mike Pagliarulo (3-8)
- Homeruns
  - Kent Hrbek (1 HR)
  - Chili Davis (2 HR)
  - Mike Pagliarulo (1 HR)
- RBI
  - Kent Hrbek (2 RBI)
  - Chili Davis (4 RBI)
  - Brian Harper (1 RBI)
  - Shane Mack (1 RBI)
  - Mike Pagliarulo (2 RBI)
- Pitcher W/L record
- Pitcher/Batter handedness (R; L,L,R,R,L)
- Batting stance

Irrelevant

- Uniform color(s)
- Player numbers (29, 23, 14, 44, 12, 24, 13)
- Player age

Enabling

- Players in field
- Batter in box
- Player at bat
- Pitcher on mound

Events

Event A

- Kent Hrbek
- Pitch count (3)
- Outs (0)
- Lineout to RF (David Justice)
- John Smoltz
- Balls/strikes
  - Fastball (Ball; High) (1-0)
  - Off-Speed (Ball; Low-In) (2-0)
  - Fastball (Hit; High)

Appendix A. Baseball Recollection Rubric (1991), p. 1

Event B

- Chili Davis
- Pitch count (4)
- Outs (1)
- Struck out looking
- John Smoltz*
- Balls/strikes
  - Fastball (Foul; High) (0-1)
  - Fastball (Foul; High) (0-2)
  - Off-Speed (Ball; High) (1-2)
  - Off-Speed (K; Low-In)

Event C

- Brian Harper
- Pitch count (4)
- Outs (2)
- Single to CF (Line drive to deep SS-2B)
- John Smoltz*
- Balls/strikes
  - Fastball (Ball; Low-Away) (1-0)
  - Off-Speed (Strike; Middle) (1-1)
  - Off-Speed (Foul; Low-Away) (1-2)
  - Off-Speed (Hit; Low-Away)

Event D

- Shane Mack
- Pitch count (5)
- Outs (2)
- Brian Harper on 1B (Advances)
- Single to CF (Ground ball thru SS-2B)
- John Smoltz*
- Balls/strikes
  - Fastball (Strike; Middle-Away) (0-1)
  - Fastball (Ball; High-Middle) (1-1)
  - Off-Speed (Strike; Low-Away) (1-2)
  - Off-Speed (Ball; Low-Away) (2-2)
  - Fastball (Hit; High-Away)

Event E

- Mike Pagliarulo
- Pitch count (5)
- Outs (2)
- Brian Harper on 2B
- Shane Mack on 1B
- Groundout 1B-P (Bream to Smoltz)
- John Smoltz*
- Balls/strikes
  - Off-Speed (Strike; Low) (0-1)
  - Fastball (Ball; High-In) (1-1)
  - Fastball (Ball; Low-Middle) (2-1)
  - Off-Speed (Strike; Low-In) (2-2)
  - Off-Speed (Hit; Low-In)

Nongame Actions

Relevant

- Catcher returns ball to pitcher
- Batter steps in/out of box
- Pitcher steps on/off mound
- Catcher gives sign
- Base Coach gives sign
- Coach visits mound
- Players warm up in bullpen

Irrelevant

- Tom Glavine sitting in dugout
- Walter Johnson mentioned during broadcast
- Chili Davis sign in crowd
- Crowd cheering after Brian Harper hit
- Ron Gardenhire (3B Coach) mentioned by broadcasters
- Wayne Terwilliger salary mentioned by broadcasters

Appendix A, Baseball Recollection Rubric (1991), p. 2

Appendix B. Baseball Recollection Rubric (1993)

Context

General

- Toronto Blue Jays
- Team pitching
- Inning
- Score
- Philadelphia Phillies
- Team batting
- Weather conditions
- Location

Specific

Relevant

- Batting averages
  - Lenny Dykstra (.348)
  - Mariano Duncan (.357)
  - John Kruk (.364)
- Hits
  - Mickey Morandini (1-3)
  - Lenny Dykstra (1-3)
  - Mariano Duncan (1-4)
  - John Kruk (0-2)
- Walks
  - Lenny Dykstra (1 BB)
  - John Kruk (2 BB)
- Homeruns
  - Lenny Dykstra (1 3R HR)
- RBI
- Run
  - Mickey Morandini (1 R)
- Stolen Base
  - Mariano Duncan (1 SB)
  - Lenny Dykstra (37 SB; 4 SB)
- Pitcher W/L record
- Pitcher/Batter handedness (L,L,R,L)
- Teams that overcame 4-run deficit graphic

Irrelevant

- Uniform color(s)
- Player numbers
- Player age

Enabling

- Players in field
- Batter in box
- Player at bat
- Pitcher on mound

Appendix B, Baseball Recollection Rubric (1993), p. 1

Events

Event A

- Mickey Morandini
- Pitch count (4)
- Outs (0)
- Strike out (missed bunt attempt)
- Al Leiter
- Balls/strikes
  - Off-Speed (Strike; Low-Away) (0-1)
  - Off-Speed (Strike; Low-Away) (0-2)
  - Off-Speed (Ball; High-Away) (1-2)
  - Off-Speed (K; Low-Away)

Event B

- Lenny Dykstra
- Pitch count (4)
- Outs (1)
- Unintentional Walk
- Al Leiter*
- Balls/strikes
  - Fastball (Ball; Low) (1-0)
  - Off-Speed (Ball; Low-Away) (2-0)
  - Off-Speed (Ball-Middle-Away) (3-0)
  - Off-Speed (Walk; High-Away)

Event C

- Mariano Duncan
- Pitch count (6)
- Outs (1)
- Lenny Dykstra on 1B
- Leiter pickoff attempt
- Dykstra attempts steal, retreats
- Popfly 2B (Deep SS-2B) (Roberto Alomar)
- Al Leiter*
- Balls/strikes
  - Off-Speed (Ball; High-Away) (1-0)
  - Off-Speed (Ball; High-In) (2-0)
  - Off-Speed (Ball; High-Away) (3-0)
  - Fastball (Strike; Low-Away) (3-1)
  - Off-Speed (Strike; Low-Away) (3-2)
  - Off-Speed (Hit; High)

Event D

- John Kruk
- Pitch count (3)
- Outs (2)
- Leiter Pickoff attempt
- Groundout 3B to 1B (broken bat) (Sprague to Olerud)
- Al Leiter*
- Balls/strikes
  - Off-Speed (Strike; Middle) (0-1)
  - Off-Speed (Ball; Low-Away) (1-1)
  - Off-Speed (Hit; Low-Away)

Event E

- Lenny Dykstra steals 2B (occurs on 0-1 count during John Kruk at-bat)

Nongame Actions

Relevant

- Catcher returns ball to pitcher
- Batter steps in/out of box
- Pitcher steps on/off mound
- Catcher gives sign
- Base Coach gives sign
- Coach visits mound
- Players warm up in bullpen

Irrelevant

- Leiter's cousin wedding mentioned in broadcast
- Crowd cheers after Morandini strikeout
- Dykstra chewing tobacco
- Duncan family shown during broadcast

Appendix B, Baseball Recollection Rubric (1993), p. 2