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The Role of General Mental Ability on a Virtual Reality Prospective Memory Task

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THE ROLE OF GENERAL MENTAL ABILITY ON A VIRTUAL REALITY BASED PROSPECTIVE MEMORY TASK

by

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Abstract

Prospective memory is the ability to carry out specific actions at a future point in time. The relationship between prospective memory and general mental ability- otherwise known as intelligence, is complex. Existing prospective memory measures are limited, particularly in regard to their ecological validity. Furthermore, little research has investigated the role of general mental ability on prospective memory performance. In order to build upon extant literature on the prognostic value of general mental ability on prospective memory assessment, this study investigated the extent to which general mental ability relates to adults and older adults ability to complete and virtual-reality based prospective memory task- The Virtual Kitchen Protocol for Prospective memory (VKP-PM).

The Role of General Mental Ability on a Virtual Reality Prospective Memory Task

General mental ability, otherwise known as intelligence, is a construct that has long been used to predict an individual's ability to succeed across multiple domains (Spearman, 1904; Song et al., 2010). The relationship between general mental ability and memory is complex. General mental ability is generally linked with working memory (Conway et al., 2003; Gevins & Smith, 2000; Kaufman et al., 2013) – indeed, working memory is part of the intelligence construct on widely-used measures of cognitive functioning (e.g., the WAIS). Compared to working memory, general mental ability has less relation to recall memory (Uttl et al., 2018; Zeintl et al., 2007). Prospective memory refers to memory for intentions – that is, the ability to carry out delayed objectives at a specific time or future event (Cohen et al., 2017; Graf, 2012; Salthouse et al., 2004). Little extant research has investigated prospective memory as it relates to more broad cognitive abilities, such as general mental ability. While traditional neuropsychological tests are able to examine these cognitive processes in controlled testing environments, they are limited in their ability to capture functioning in day-to day life (Barnett et al., 2021; Burgess et al., 2006; Chaytor & Schmitter-Edgecombe, 2003). The use of virtual reality in testing environments has expanded the ecological validity of neurophysiological assessment by granting a level of realism not seen in traditional pencil and paper tests (Rizzo et al., 2004; Roberts et al., 2019). The purpose of this study was to investigate the relationship between general mental ability on a virtual reality prospective memory task, the Virtual Kitchen Protocol for Prospective Memory (VKP-PM).

Prospective Memory

Researchers have debated whether prospective memory represents a distinct type of memory or whether it is a facet of episodic memory (Crowder, 1996; Graf & Uttl, 200; Roediger, 1996). Recent studies have found evidence suggesting that prospective memory is a distinct and separate cognitive process (Gupta et al., 2010; Mäntylä, 2003; McDaniel & Einstein, 2007), differentiating it from retrospective memory (i.e., the memory for past information). Prospective memory has been broadly conceptualized into a 5-phase model: intention formation, retention delay, cue detection and intention retrieval, intention recollection, and intention execution (Zogg et al., 2012). The first stage, intention formation, is where the encoding of intention is tied to a cue that serves as a reminder for when that intention should take place and is either time-based (e.g., "I have an appointment in 2 hours") or event-based (e.g., "I have an appointment after lunch"). The second phase of retention delay refers to the time between forming the intention and the cue for its execution. This is the period of time where attention competes with other activities that prevent conscious rehearsal of the intention cue. The third stage, cue detection and intention retrieval, is considered the defining feature of prospective memory and involves cue recognition and retrieval of the intention. Intention recollection refers to the retrieval of the planned intent to remember what is to be done and lastly, intention execution, is where the intended task is done. Previous research has suggested that a multitude of areas of general mental ability, including planning, problem solving ability, cognitive flexibility and fluency, to be predictors of performance on phases of the aforementioned model (Kliegel et al., 2002; Salthouse et al., 2004).

The Virtual Kitchen Protocol for Prospective Memory

Virtual reality (VR) refers to computer-generated environments that users can explore and engage with in real time (Knight & Titov, 2009; Rizzo et al., 2004; Roberts et al., 2019). Given previous research suggesting older adults perform better on naturalistic PM tasks than traditional laboratory ones (Kourtesis & MacPherson, 2021; Niedźwieńska & Barzykowski, 2012; Weakley et al., 2019), the use of VR in testing environments has particular importance when assessing these abilities among different age groups. Known as the age paradox, this concept describes the general pattern of age-related benefits of everyday tasks carried out in routine environments and deficits that may be seen in typical neuropsychological assessment. When evaluating an individual's ability to perform instrumental tasks of daily living, the use of high dimensional approaches, such as VR, may therefore increase the ecological validity of these tests.

The Virtual Kitchen Protocol for Prospective Memory (VKP-PM) was designed to measure everyday memory performance for tasks involving meal preparation (Barnett et al., 2021). Consistent with other virtual reality-based measures of memory, the VKP demonstrated stronger correlations with verbal memory and their counterparts on the CVLT-II and moderate correlations between visual memory counterparts (WMS-IV VR I & II; Barnett, et al., 2021). Previous research has found preliminary validity in the VKP-PM as a prospective memory measure and its utility for identifying cognitive decline in prospective memory (Barnett & Coldiron, under review).

Prospective Memory and General Mental Ability

While the nature of intelligence, and what factors constitute it, has long been argued, Spearman's *g* is by far the most widely accepted construct of what is understood as cognitive ability (Flynn, 2007; Lubinski, 2004). Comprising a multitude of skills ranging from verbal, mechanical, spatial, and numerical, Spearman (1904) argued that performance in one area of intelligence is strongly correlated to others (Brody, 1999; Flynn, 2007). Furthermore, research has also identified the area of working memory, specifically prospective memory, as being one of the strongest correlates to measures of intelligence (Oberauer et al., 2005; Salthouse et al., 2004; Uttl et al., 2018). Sizeable associations were found between prospective memory and measures of cognitive ability (Salthouse et al., 2004; Kliegel et al., 2002). More specifically, episodic prospective memory was correlated with processing speed, working memory, crystallized/verbal intelligence, and fluid/performance intelligence measures. Oberauer et al. (2005) found that working memory capacity is a very strong predictor of reasoning ability and predictor of general fluid intelligence and *g*. Furthermore, specific general mental abilities have been linked to certain phases within the prospective memory model (Kliegel et al., 2002). In the area of intention formation, planning was identified as the most important executive function while cognitive flexibility and problem-solving skills were significantly correlated with performance in the intention recollection phase. Lastly, higher levels of cognitive fluency and cognitive flexibility reflected better performance in the last phase of intention execution. These findings suggest the increased likelihood of general mental ability not only relating to measures of prospective memory, but as a possible explanation for performance on these tasks. However, no extant study has investigated the VKP-PM in relation to general mental ability.

The Current Study

The purpose of this study is to investigate the extent to which general mental ability relates to the ability of adults and older adults to complete a virtual-reality based prospective memory task, the VKP-PM. Our hypothesis was that general mental ability would be associated with greater prospective memory performance. While previous research (Barnett & Coldiron, under review; Hering et al., 2014; Niedźwieńska et al., 2020) has found evidence of possible age cohort differences in prospective memory performance, no extant study has investigated whether general mental ability relates to virtual reality-based measures of prospective memory performance.

Method

Participants

This study utilized archival data. Participants (*N* = 152) consisted of adults and older adults. The adult sample (*n* = 82) consisted of college students recruited by the universities SONA system, a website where students can volunteer to participate in research for extra credit in their classes. These participants were ages 18 to 64 (*M* = 30.59, *SD* = 18.16), 67.1% female, 30.5% male, and 2.4% Other/prefer not to respond. The adult participants identified as White/Caucasian (84.1%), Black/African American (2.4%), Native Hawaiian/Other Pacific Islander (2.4%), American Indian/Alaskan Native (1.2%), Other (1.2%) and 8.5% preferred not to respond. Of these individuals, 14.6% identified as Hispanic (4.9% preferred not to respond).

The older adult sample (*n* = 70) was recruited by public announcement from community groups, organizations, senior living centers or by the local Alzheimer's Alliance and other healthcare providers. This sample consisted of participants ages 65-90 (*M* = 75.09%, *SD* = 5.97), 51.4% female, 38.6% male, and 10% Other/prefer not to respond. The older adult participant sample identified as 81.4% White/Caucasian, 7.1% Black/African American, and 11.4% preferred not to respond.

Measures

Virtual Kitchen Protocol for Prospective Memory (VKP-PM)

The VKP-PM is a virtual reality measure of prospective memory and includes four event-based cues (e.g., "when you hear a knock") and four time-based cues (e.g., "in five minutes"), both of which include two cues with short delays of 3-5 minutes and two with longer delays of 11-13 minutes (Barnett et al., 2021). The nature of virtual reality allows for a more life-like experience that captures a better reflection of prospective memory and the activities of daily living that are often impacted by it. As such, the VKP-PM consists of intentions, such as cooking an egg, that an individual would complete while in their home. These intentions are scored on accuracy of the task and accuracy of timing. Both are on a 0 to 2 scale that is then combined for a total intention score ranging from 0 to 4. Task accuracy is scored on a 0 to 2 scale, 2 for accurate completion, 1 for partial completion, and 0 for no task completion. Task accuracy is similarly scored on a 0 to 2 scale (2 for exact time +/- one minute, 1 for completion at any other time, and 0 for no completion). All scores are then summed by event or time-based cue and length of delay for a total VKP-PM prospective memory score. To serve as a distraction, a true or false verbal task was created where participants hear a recording of sentences that they have to respond verbally. These items are scored as either correct or incorrect. In order to measure retrospective memory in a separate component from the prospective memory task, a multiple-choice recognition task is completed afterwards.

Wechsler Adult Intelligence Scale 4th Edition (WAIS-IV) – Selected Subtests

The Wechsler Adult Intelligence Scale – IV is an individually-administered test of intellectual functioning (Wechsler, 2008). Four WAIS-IV subtests were administered, one from each of the four indexes: Vocabulary, Block Design, Digit Span, and Coding. In the Vocabulary subtest, an individual is presented with words and asked to define them. As a direct assessment of word knowledge, this subtest is one indication of overall verbal comprehension. Performance on this subtest may be considered a reflection of language acquisition and the ability to verbalize meaningful concepts and retrieve information from long-term memory. In order to assess and individuals understanding of complex visual information, spatial perception, and problem solving skills, the Block Design subtest asks participants to copy two-dimensional designs using three-dimensional blocks. It also requires fine motor control, visuospatial planning, and relatively quick reasoning as the task is timed. The Digit Span subtest is comprised of three parts, Digit Span Forward (where the individual is asked to repeat a sequence of digits and say them back to the examiner, Digit Span Backward (requiring the examinee to repeat a sequence of digits in reverse order), and Digit Span Sequencing (where the individual is asked to repeat digits in ascending order). This task is one measure of working memory, cognitive flexibility, attention and encoding. Performance on this task may additionally be considered a reflection of verbal short-term memory and concentration. As a measure of processing speed, short-term memory, and psychomotor speed, the Coding subtest requires an individual to pair a set of symbols with paired numbers and then copy the correct symbol for a string of randomized numbers. This test was designed to reflect an individual's visual-motor coordination, visual scanning, and other cognitive abilities such as learning. The age-corrected subtest scores will be aggregated into a composite score (see Data Analysis Plan below).

Procedures

This study utilized archival data from two research projects approved by committee for the protection of human subjects at The University of Texas at Tyler. Informed consent was obtained from all participants before their participation. Participants completed a battery of neuropsychological tests that included the selected WAIS-IV subtests as well as the Virtual Kitchen Protocol. Older adult participants completed a clinical interview and, where possible, a collateral interview was conducted.

Data Analysis Plan

In order to form a composite score, exploratory factor analysis was performed on the age-corrected WAIS-IV subtest scores. Principal axis factoring was used to extract a single component. This composite score represents general mental ability. A hierarchical regression analysis was conducted using IBM SPSS Statistics (Version 29.0). In this model, age cohort was the independent variable in block one, general mental ability was the independent variable in block two, and the VKP-PM total raw score was the dependent variable. In order to isolate the effects of education, as education level has been known to correlate with general mental ability, education was added as an independent variable (Plassman et al., 2012; Ritchie & Tucker-Drob, 2018; Spinath et al., 2006). The study hypothesis (i.e., that general mental ability contributes to prospective memory) was confirmed by the existence of a linear relationship between the general mental ability composite score and the VKP-PM total score.

Results

As with previous research (Lawrence et al., 2010), the four WAIS-IV subtest scale scores were highly correlated with each other and thus could not be included in a multiple regression analyses as separate independent variables due to multicollinearity. Therefore, we sought to condense these four scores into a composite score. To do so, exploratory factor analysis was performed on the age-corrected WAIS-IV subtest scores. Principal axis factoring was used to extract a single component. This composite score represents general mental ability.

A hierarchical regression analysis was conducted using IBM SPSS Statistics (Version 29.0). In this model, age cohort was the independent variable in block one, general mental ability was the independent variable in block two, and the VKP-PM total raw score was the dependent variable. Bivariate correlations and descriptive statistics are displayed in Table 1. In order to test the prediction above, a hierarchical regression was conducted with two blocks of variables. The first block included age cohort (1 = adult, 2 = older adult) as the independent variables, with VKP-PM total raw score as the dependent variable. In block two, the composite of age-corrected WAIS-IV subtests scores representing general mental ability was also included as a predictor variable. Results of this hierarchical multiple regression are displayed in Table 2. Due to the known correlates between education level and general mental ability, Table 3 additionally included years of education as an independent variable.

Overall, the results showed that the first step of the regression, with age cohort as the only predictor, explained 19.9% of the variance, $F(1,150) = 37.157$, $p < 0.001$. In the second step of the regression, which included both age cohort and general mental ability as independent variables, additional variance was explained ($R^2\Delta = 14.1$, $F(1, 149) = .199$, $p < 0.001$). Age cohort and general mental ability explained 33.1% of the variance in VKP-PM performance, *adjusted* $R^2 = 0.331$, $F(2, 149) = 38.332$, $p < 0.001$. Both age cohort ($\beta = -0.466$, $p < 0.001$) and general mental ability ($\beta = 0.376$, $p < 0.001$) were significant predictors of VKP-PM performance. The third step of the regression, which included years of education, explained an additional 15.6 % of variance ($R^2\Delta = 15.6$, $F(1, 137) = .220$, $p < 0.001$.

Discussion

General mental ability is a well-researched concept with an abundance of evidence supporting its capacity to predict success across a multitude of life's domains, including academic achievement and job performance (Salgado & Moscoso, 2019; Song et al., 2010). While the connection between general mental ability and various cognitive domains is quite complex, research has consistently linked it with a specific type of memory responsible for retaining readily accessible information – that is, working memory (Conway et al., 2003; Gevins & Smith, 2000; Kaufman et al., 2013). Falling under this scope is one's memory for future events, the ability to remember to remember, or prospective memory. The purpose of this study was to investigate the relationships between general mental ability and prospective memory among young adults and older adults. This is of particular importance when considering the age-related paradox, indicating that older adults perform worse than younger adults on prospective memory tasks in research laboratory settings than when compared to more naturalistic settings (Henry et al., 2004; Kamat et al., 2014; Niedźwieńska et al., 2020). Virtual reality measures may therefore increase the ecological validity of neuropsychological assessments by allowing for a degree of realism not traditionally seen in standard pencil and paper tests (Rizzo et al., 2004; Roberts et al., 2019). To this end, this study investigated the extent to which general mental ability related to the ability of different age cohorts (young adults and older adults) to complete a virtual-reality based prospective memory task, the VKP-PM.

Results supported the hypothesis since lower performance on measures of general mental ability correlated with lower scores on the VKP-PM. This suggests that general mental ability is predictive of prospective memory involved in everyday and kitchen tasks. These results are consistent with previous research suggesting the influence of higher-level cognitive functioning when predicting the distinct and separable processes involved in prospective memory (Oberauer et al., 2005). General mental abilities and prospective memory abilities are particularly associated with each other, in fact, 14.9% of variability in prospective memory performance was explained by cognitive ability variables (Uttl et al., 2018). Executive cognitive functions such as prioritization, coordination, and the sequencing of distinct tasks elements have been suggested as underlying prospective memory processes (Kliegel et al., 2002). Planning was found to be the most crucial executive function, and performance during the intention recollection phase was substantially connected with cognitive flexibility and problem-solving abilities during intention formation. Furthermore, higher degrees of cognitive flexibility and cognitive fluency were associated with improved performance during the last stage of intention execution. Further research on the predictive validity of intelligence measures should build upon the preliminary validity of virtual reality-based measures of prospective memory such as the VKP-PM and traditional valid measures of pen-and-paper measures.

While the results of this study add to current literature on the prognostic value of general ability on the virtual assessment of prospective memory, there were several limitations to the study that must be considered. Firstly, the convenience of the samples are incongruent with representative national demographics, as they were collected in the East Texas area as part of broader neuropsychological studies for The University of Texas at Tyler. As the sample of adults in this study were recruited through the universities SONA system, that population consisted entirely of those enrolled at the university, which does not accurately reflect a diverse array of education levels that may be seen in the general public. Moreover, the samples, particularly the older adult sample, primarily identified as White/Caucasian, limiting how generalized the findings for minority adult populations. Furthermore, since cohort effects cannot be completely ruled out, comparing age cohort samples restricts the degree to which findings may be extended to the true nature of healthy aging. Finally, as participants' general mental ability performance was comprised of a composite score of what is considered as general intelligence, consisting of age-corrected WAIS-IV subtest scores, the support of the validity and clinical utility of these finding is supplementary in nature to previous findings at this time.

Overall, the current study advances the current literature on the important role that general mental ability plays in prospective memory and suggests critical directions for prospective memory research into the impact of cognitive factors. This study also furthers the validity of the Virtual Kitchen Protocol for Prospective Memory (Barnett et al., 2021) as a virtual reality-based neuropsychological measure of prospective memory. Additionally, with utilization of novel virtual reality scenarios, neuropsychological assessment can be advanced when measuring daily and complex cognitive abilities such as prospective memory general intelligence. The results of this study not only indicate the advantage of modern technology when measuring complex cognitive functioning, but the predictive nature of general mental ability when measuring prospective memory, advancing functionality of neuropsychological assessment.

Table 1

Descriptive Statistics and Correlations for Study Variables

Variable	*N*	*M*	*SD*	1	2	3
1. Virtual Reality Prospective Memory Total (Time-Based + Event-Based)	152	19.09	9.970	-	-0.46*	0.351*
2. Age Cohort	152	1.46	0.500		-	.053
3. General Mental Ability Composite	152	.000	0.751			-

*$p < .001$

Table 2

Model Summary

Model	R	R^2	Adjusted R^2	SE of the Estimate	$R^2 \Delta$	Change Statistics			
						$F\Delta$	df1	df2	Sig. $F\ \Delta$
1	0.456[a]	0.199	0.193	8.955	0.199	37.157	1	150	< .001
2	0.583[b]	0.340	0.331	8.155	0.141	31.862	1	149	< .001

Note. *SE* = standard error; a. Predictors: (Constant), Age Cohort; b. Predictors: (Constant), Age Cohort, General Mental Ability Composite.

Table 3

Regression Coefficients

Model		*B*	*SE* β	β	*t*	*p*	95.0% CI for *B*		Collinearity Statistics	
							LL	*UL*	Tolerance	VIF
1	Years of Education	-.090	0.247	-.031	-0.363	0.717	-0.578	0.399	1.00	1.000
2	Years of Education	-.015	0.219	-.005	-.067	0.47	-0.448	0.419	.997	1.003
	Age Cohort	-9.558	1.531	-0.470	-6.245	<.001	-12.584	-6.531	.997	1.003
3	Years of Education	-0.187	0.199	-.064	-0.939	0.349	-0.580	0.207	.975	1.025
	Age Cohort	-9.926	1.375	-0.488	-7.220	<.001	-12.645	-7.208	.995	1.005
	General Mental Ability Composite	5.315	0.906	0.400	5.864	<.001	3.522	7.107	.975	1.025

Note. SE= standard error; CI = confidence interval; *LL* = lower limit; *UL* = upper limit; VIF = variance inflation factor.

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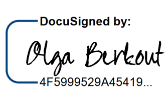

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