

Working Memory Capacity, Cognitive Regulation, and Their Relationship to Academic Achievement in University Students

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Abstract

The present study investigates the relationship between working memory capacity, cognitive regulation, and academic achievement for university students. Additionally, it examines whether working memory capacity and/or cognitive regulation can predict academic achievement. For the 139 university students who took part in the study, working memory capacity was measured via a digit span test, cognitive regulation was measured via the MAI (Metacognitive Awareness Inventory), and academic achievement was measured via GPA. The results indicate that there is a significant relationship between working memory capacity and cognitive regulation ability, that cognitive regulation had a marginally stronger correlation with GPA than working memory capacity did, and that the working memory ability and cognitive regulation model was a good predictor of academic achievement for the sample studied.

Keywords: working memory, cognitive regulation, cognitive monitoring, GPA

1. Introduction

Academic performance has always been the center of attention of researchers from a variety of fields, such as education, educational psychology, education policy, and cognitive science, because it is the primary indicator of success in academia. Academic performance has always been linked to intellectual and affective factors such as intelligence, motivation, self-efficacy, strategic behavior, use of cognitive and metacognitive strategies, resilience, and self-regulation, among other factors. Two of the factors that have received interest from researchers in the last decade are factors related to executive function such as working memory capacity, and factors related to metacognition such as cognitive monitoring and control.

Working memory refers to people's ability to hold information temporarily and manipulate it in their minds (Gathercole & Alloway, 2008). More specifically, it refers to a cognitive system with a number of resources to store information while at the same time perceive and process new incoming information and or stimuli necessary for the completion of other cognitively demanding tasks (Conway, Jarrold, Kane, Miyake, & Towse, 2007). According to Cowan (2017), working memory is the capacity to store, retain, and retrieve previous information and is a multifaceted memory system that intervenes in the regulation of executive control and selective attention functions while involved in cognitively demanding tasks.

Working memory is central to the execution of complex cognitive processes such as reasoning, problem solving, and language comprehension. Much like cognitive regulation, which refers to the online monitoring and control of one's cognitive resources while engaging in tasks such as reading comprehension, studying, and memorizing.

Cognitive regulation on the other hand refers to cognitive monitoring and control processes that operate to guide thinking, learning, language comprehension, or basically any task that involves thinking/cognition. While cognitive monitoring ability refers to the online assessment of one's thinking while engaging in cognitive tasks, cognitive control refers to the adjustments one makes as a result of feedback from monitoring in order to optimize thinking, reasoning, or memory during task performance (Amzil, 2013; Amzil & Stine-Morrow, 2013).

There is evidence in the literature that reported strategic behavior, accounts for individual differences in working memory. In other words, working memory span is higher for individuals who reported using higher cognitive monitoring strategies (Dunlosky & Kane, 2007; Turley-Ames & Whitfield, 2003). There is also evidence that the behavior that guides working memory ability during task performance is mediated by metacognitive monitoring and control (Touron, Oransky, Meier, & Hines, 2009). However, most of this evidence comes from studies

where working memory is the outcome measure and not overall academic performance.

Additional evidence on how cognitive regulation mediates working memory ability comes from the psychology of aging literature where there seems to be consensus that cognitive monitoring ability dramatically declines with age (Dunlosky & Hertzog, 2000) and that age differences in cognitive monitoring ability account for differences in working memory task performance (Castel, Middlebrooks, & McGillivray, 2016; Hertzog & Dixon, 1994). These findings are argued to be the result of a declining ability in older adults to use appropriate cognitive control strategies as a result of a declining cognitive monitoring ability; which in turn, affects working memory capacity (Zhou, Lu, & Dong, 2017; Dunlosky & Connor, 1997). Similar results were reported by Freeman, Karayanidis and Chalmers (2017), who investigated the metacognitive regulation of working memory and how it related to academic achievement in Grade 4 children. Their results showed that academic achievement was higher for children who had a more accurate metacognitive monitoring of working memory, and that metacognitive monitoring of working memory was good predictor of mathematical ability. Additionally, they found that a significant relationship between metacognitive calibration, which is a regulatory function of metacognition, and four measures of academic achievement, namely, words reading, numerical operations, and spelling ability.

The above-mentioned evidence seems to overlap with results from a more recent study by Quilez-Robres, Moyano, and Cortes-Pascual (2021), who found out that there is a relationship between academic achievement and different aspects of executive functions, including working memory, and task monitoring. In their study, Quilez-Robres, Moyano, and Cortés-Pascual, built on the existing evidence that connects academic achievement to executive functions such as initiative, working memory, task monitoring, organization of materials, flexibility, emotional control, inhibition, and self-monitoring, to investigate how these differentially predict general academic achievement, and achievement in specific areas such as Language Arts and Mathematics. Their results show that there is no substantial difference between the correlation for general academic achievement and specific achievement but that working memory and monitoring ability had the stronger relationship with both types of achievement.

It is clear in the literature that working memory and cognitive regulation interact with different outcome measures such as reading ability, language comprehension, and ability to recall, however, it is not clear if these two variables interact with one another and impact overall academic achievement for university students. Furthermore, given the evidence for the interaction of working memory capacity and cognitive regulation with general cognitive ability, it is worth investigating the effectiveness of both variables as model, in predicting GPA for university students.

The present study attempts to explore the relationship between cognitive regulation (monitoring and control), working memory capacity, and academic achievement for university students. In the same vein, it will examine the extent to which cognitive regulation (monitoring and control), and working memory capacity can predict academic performance for the sample studied.

1.1 The Current Study

The current study examines the relationship between cognitive regulation (monitoring and control), working memory capacity, and academic achievement for Moroccan university students. More specifically, it attempts to explore how cognitive regulation, measured via the metacognitive regulation factor in the Metacognitive Awareness Inventory (MAI) (Shraw & Dennison, 1994) relates to working memory capacity measured via a digit span test, and if these can predict academic achievement for Moroccan university students. Hence, the research questions for the present study are as follows:

- Is there a relationship between cognitive regulation and working memory capacity?
- How do cognitive regulation and working memory capacity relate to academic achievement?
- How do cognitive regulation and working memory capacity predict academic achievement?

2. Method

2.1 Participants

139 students from the Faculty of Education, Rabat were the participants in this research. The group consisted of 79 females and 60 males with an age range between 18 and 25 years, inclusive. Of the 138 students, 30 are graduate students and 109 are undergraduates.

2.2 Instruments

Working memory was measured via a digit span test that presents participants with a series of digits with an

immediate recall test. This test measures working memory using a forward digit span and a backward digit span. While the first requires recall of a series of digits that increase by one digit every two trials, the second requires a recall of the digits in reverse order. The participant's span is the longest number of numerical sequential digits he/she can remember in the order in which they were presented for the forward digit span and in reverse order for the backward digit span test. In both tests, the digits are presented in at the rate of one per second.

The digit span test is a well-established measure of working memory capacity and a known subset of the Wechsler Adult Intelligence Scale (WAIS), which is a widely used and reliable measure of a large battery of cognitive and affective attributes among which is working memory capacity. While the forward digit span test has a reliability coefficient of .81, the backward digit span test has a reliability coefficient of .82 (Gignac, Reynolds, & Kovacs, 2017).

Cognitive regulation was measured using the regulation of cognition factor of the Metacognitive awareness inventory (Schraw & Dennison, 1994). The regulation of cognition factor includes 35 self-report items that tap students' metacognitive monitoring and control abilities through a 5-point Likert scale (Amzil & Stine-Morrow, 2013). The score generated reflects the respondents' metacognitive regulation abilities, and has a reliability coefficient of .87 (Schraw & Dennison, 1994).

Finally, academic performance was measured via cumulative GPA of the participants who all signed consent forms to allow the researcher access to scores. Cumulative GPA has consistently been used as a reliable measure of academic performance in research since it relies on scores from different modules and subjects per year.

2.3 Procedure and Data Analysis

The present study is exploratory and uses an ex-post facto research design to examine potential connections between variables after occurrence. Through correlation, the study looked for likely connections between working memory capacity, cognitive regulation, and academic performance for graduate and undergraduate Moroccan University students. Furthermore, regression analysis was run in order to see if working memory capacity and/or cognitive regulation can predict academic achievement for Moroccan students.

Students were sent a link to the Metacognitive Awareness Inventory online through Microsoft Forms, and were also sent a link to take the digit span test (forward and backward). The Form that students had access to included an introduction to explain the procedure to them and asked for demographics such as name, gender, and level of studies. There was a section where students were asked to report on their digit span test scores. Finally, a consent form was attached where the students gave the researcher permission to access their GPA scores.

Data was analyzed in SPSS and normality of the data was checked via the Shapiro Wilk Normality test. Since the data was normally distributed, Pearson's correlation was used to detect likely connections between the variables, and a simple linear regression analysis was used to check the size of the variance in GPA that can be explained by working memory capacity and cognitive regulation. It is worth noting that, for the regression analysis, the backward digit span scores and forward digit span scores were grouped into one composite score that reflects working memory ability as a whole. The following section will detail the results for the two tests used and describe the graphs and figures.

3. Results

3.1 The relation between working memory capacity and cognitive regulation

Table 1. Correlations between working memory scores and cognitive regulation scores

		Forward Digit Span	Backward Digit Span	Cognitive Regulation
ForwardDigitSpan	Pearson Correlation	1	.580**	.261**
	Sig. (2-tailed)		.000	.002
	N	139	139	139
BackwardDigitSpan	Pearson Correlation	.580**	1	.334**
	Sig. (2-tailed)	.000		.000
	N	139	139	139
CognitiveRegulation	Pearson Correlation	.261**	.334**	1
	Sig. (2-tailed)	.002	.000	
	N	139	139	139

Note. **Correlation is significant at the 0.01 level (2-tailed).

Correlations between the participant's scores in the forward digit span, the backward digit span, and cognitive regulation were calculated. The results show a significant positive correlation between the forward digit span and cognitive regulation, and a significant positive correlation between the backward digit span scores and cognitive regulation. Interestingly, cognitive regulation seems to correlate more strongly with working memory capacity measured by the backward digit span than the forward digit span.

Table 2. Correlation between GPA, working memory scores, and cognitive regulation scores

		ForwardDigitSpan	BackwardDigitSpan	CognitiveRegulation
GPA	Pearson Correlation	.488**	.510**	.539**
	Sig. (2-tailed)	.000	.000	.000
	N	139	139	139

Note. **Correlation is significant at the 0.01 level (2-tailed).

The results show a positive significant correlation between GPA and both measures of working memory capacity, with a slightly stronger correlation for the backward digit span. The table also shows a significant positive correlation between GPA and cognitive regulation, which correlates slightly stronger with GPA than working memory capacity.

Table 3. Analysis of variance for the cognitive regulation and working memory capacity model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	163.263	2	81.631	56.566	.000 ^b
	Residual	196.265	136	1.443		
	Total	359.528	138			

Note. a. Dependent Variable: GPA; b. Predictors: (Constant), Cognitive Regulation, Working Memory Capacity.

Multiple regression analysis was used to test if cognitive regulation and working memory capacity significantly predict the students' academic performance measured by GPA.

The ANOVA table above shows that the regression fits the data and that the model proposed notably, cognitive regulation and working memory predicts the dependent variable GPA. In other words, the regression is statistically significant and predicts the outcome measure/variable. The significance of the model can be reported as $F(2, 136) = 56.566, p = 0$.

Table 4 on the other hand, shows the model summary and provides the correlation score for the model $r = .67$, and the R square value which demonstrates that the predictors (working memory capacity and cognitive regulation) explained 45.4% of the variance in the dependent variable $R^2 = .45, F(2, 136) = 56.566, p = 0$.

Table 4. Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.674 ^a	.454	.446	1.20130

Note. a. Predictors: (Constant), Cognitive Regulation, Working Memory Capacity; b. Dependent Variable: GPA.

It was also found (see Table 5) that cognitive regulation significantly predicted GPA $\beta = .39, t(2, 136) = 5.886, p = 0$. A plus one increase in the score of cognitive regulation corresponded on average to an increase of .78 in GPA, $B = .78, 95\% \text{ CI } [.518, 1.042]$. Finally, it was found that working memory capacity significantly predicted GPA, though to a lesser extent than cognitive regulation, $\beta = .429, t(2, 136) = 6.378, p = 0$. A plus one increase in the working memory capacity score corresponded on average to an increase of .28 in GPA, $B = .28, 95\% \text{ CI } [.193, .366]$.

Table 5. Regression results using GPA as the criterion

Model		Unstandardized		Standardized	t	Sig.	95.0% Confidence Interval for B	
		Coefficients		Coefficients			Lower Bound	Upper Bound
		B	Std. Error	Beta				
1	(Constant)	7.351	.552		13.314	.000	6.259	8.443
	Working Memory Capacity	.280	.044	.429	6.378	.000	.193	.366
	Cognitive Regulation	.780	.132	.396	5.886	.000	.518	1.042

Note. a. Dependent Variable: GPA.

4. Discussion

The main goal of the research was to explore potential connections between cognitive regulation and working memory capacity, and how these relate to academic achievement measured by GPA.

The study also investigated if a model composed of cognitive regulation and working memory capacity can predict academic achievement for the sample studied.

When it comes to the first objective, the results showed a positive relationship between cognitive regulation and working memory capacity. More specifically, there was a significant positive correlation between cognitive regulation and both measures of working memory capacity. However, it is worth noting that the backward digit span test correlated more strongly with cognitive regulation than the forward digit span test. This connection between cognitive regulation and working memory capacity is likely because working memory capacity intervenes in the monitoring phase of cognitive regulation since the latter refers to the online assessment of one's cognitive abilities and resources on task. Holding on to information about a cognitively demanding task while at the same time reflecting on one's own attention, resource allocation, and strategy use would solicit efficient use of working memory resources. This online reflection on the cognitive resources needed to complete a task while performing the task is what informs the second phase of cognitive regulation, i.e., cognitive control. As a result of this process, and if one's metacognitive judgments about task requirements are accurate and calibrated, the control phase of cognitive regulation allocates the right strategies, amount of attention, and/or general cognitive resources to perform the task successfully. This relates to findings by Amichetti et al. (2013) who described the relationship between working memory capacity and cognitive regulation as resulting in an ability to calculate availability of resources to fulfil tasks. This online capacity monitoring, they argued, is a form of working memory executive function, which is hindered when attentional resources are strained.

Concerning the second objective of the current study, notably, investigating the relationship working memory capacity measured by the forward and backward digit span, and GPA, there was a significant correlation between GPA and both measures of working memory capacity. The results for this research question also indicate a stronger correlation of working memory capacity measured by the backward digit span than with the forward digit span. In other words, although GPA significantly relates to both measures of working memory capacity, the backward digit span test seems to correlate slightly significantly stronger with GPA than the forward digit span although the tests significantly correlate with one another. This connects to findings by Delaney, Godbole, Holden and Chang (2017), and Holden, Goodwin and Conway (2020) who found significant connections between working memory capacity and performance in a number of cognitive ability tests.

GPA was also found to be significantly related to cognitive monitoring, slightly more so than it did with working memory capacity. This finding supports findings by a number of researchers (Everson & Tobias, 1998; Zulkiply, Kabit, & Kartini, 2008) who found that regulation of cognition accuracy significantly correlated with end of course grades in English, the humanities, and the students' overall GPA. The results also show evidence that cognitive regulation affects different facets of learning such as acquisition of language, language comprehension, retention, as well as skills such as critical thinking and problem solving (ibid). This connection between working memory capacity, cognitive regulation, and academic performance confirms views by researchers such as Komori (2016), who concludes that monitoring is an executive function of working memory that provides updated information on task-relevant objectives and eliminates task-irrelevant noise, hence resulting in more efficient thinking, learning, problem solving...etc.

Finally, the results from the regression analysis demonstrate that cognitive regulation and working memory capacity are good predictors of academic achievement measured by GPA, and that cognitive regulation on its own is an even stronger predictor of academic achievement. This suggests that working memory capacity works as a mediator of metacognitive regulation, which is the more directly linked factor to academic achievement.

Results from Komori (ibid) also seem to corroborate the present findings in that accurate cognitive regulation requires high working memory capacity, and that in turn results in improved metacognitive abilities that result in improved cognitive performance. This corroborates findings reported by Quílez-Robres, Moyano and Cortés-Pascual (2021) who found that working memory ability and monitoring ability were effective predictors of general academic achievement and for Language specific achievement in Language Arts, and Mathematics.

In conclusion, the results of the present research confirmed that there is a connection between working memory capacity and cognitive regulation, and that they both interact to predict academic achievement for university students.

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