USING METACOGNITIVE GUIDANCE TO FACILITATE "ACTIVE LEARNING" IN ADHD

by

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A thesis submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Arts in
Psychology

Charlotte

2019

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ABSTRACT

MEAGAN PAIGE PADRO. Using metacognitive guidance to facilitate "active learning" in ADHD. (Under the direction of DR. DOUGLAS MARKANT)

Modern education, at all levels, is shifting to active learning techniques. Active learning requires students to engage in meaningful learning activities and continuously monitor what they are doing. Research on active learning techniques in the classroom have yielded increased student learning outcomes above and beyond those achieved by the traditional lecture format. This enhancement has been proposed to arise from a number of mechanisms including metacognition. Metacognition is commonly described as "knowing about knowing": it is our awareness of and control over our cognitive processes. For individuals with ADHD, who have impaired executive functioning capabilities, breakdowns could occur in metacognitive processes, limiting their ability to accurately monitor what has been learned. The goal of the current study was to determine if the inclusion of guided metacognitive monitoring, in the form of judgments of learning (JOLs), influences participants' control of study choices and thus long-term retention of learned material. Overall, there was a positive effect of prompted monitoring on accuracy where the inclusion of JOL ratings led to significant improvements in test performance. Results also provide support for an effect of individual differences in executive functioning on metacognitive monitoring and control and test performance. These results support the incorporation of JOLs as a promising avenue for modifications to active learning techniques that may be advantageous for those with deficits in executive functioning.

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ADHD	attention deficit hyperactivity disorder
EF	executive functioning
HC	healthy control
JOL	judgment of learning
SSRT	stop signal reaction time
WMC	working memory capacity

CHAPTER 1: INTRODUCTION

Modern education, at all levels, is shifting to learner-centered pedagogical approaches. Although a wide variety of educational philosophies touch on a common theme of learner-centered experience, *active learning* refers to a broad range of teaching strategies which engage students as active participants in their learning. Implementation of the approach can take many forms, and be executed in any discipline, but commonly, students engage in individual or group activities centered around writing, talking, problem solving, or reflecting instead of being passive recipients of knowledge. Research on active learning techniques used in the classroom has demonstrated increased student learning outcomes when compared to passive learning in the traditional lecture format (Prince, 2004). Active learning involves students in their own learning process where they engage in meaningful activities, continuously monitor their progress, and exert control over decision-making during learning or study. Setting appropriate learning goals requires self-reflection and problem solving which depend significantly on students' metacognitive skills, or their ability to effectively monitor current knowledge accumulation and exert control over subsequent decisions which ultimately lead to successful learning outcomes.

Recent experimental research on active learning has shown that having volitional control over study decisions enhances memory for material compared to passive observation (i.e., no active control) of the same information (Markant, DuBrow, Davachi, & Gureckis, 2014; Voss, Gonsalves, Federmeier, Tranel, & Cohen, 2011). This enhancement has been proposed to arise from a number of mechanisms including metacognitive control of study (Markant, Ruggeri, Gureckis, & Xu, 2016). Metacognition is commonly described as “knowing about knowing”: it is our awareness of and control over our cognitive processes (Flavell, 1979). Students high in metacognitive and self-regulatory abilities are characterized by active involvement in their own learning process, continuous planning, careful monitoring of the task that they are required to complete, monitoring of their own study behaviors, and appropriate matching between task objectives and study strategies (Zimmerman, 1986). Students who are aware of the way they study and learn material can achieve more desirable outcomes than those who are less aware. In other words, students who engage in metacognitive control may ultimately learn more than those who do not.

There are a few reasons why these differences exist (Finley, Tullis, & Benjamin, 2010). Students who demonstrate metacognitive awareness are more likely to create effective personal learning environments and monitor if their current understanding is accurate. They are also more aware of misperceptions and attempt to find corroborating information to determine if their understanding is accurate. Metacognition helps regulate the flow of information through memory and relies on self-regulatory processes (i.e., one’s autonomous effort to initiate, sustain, and alter behavior, emotions, and thoughts in the pursuit of long-term goals) to influence the meaningfulness of encoding. For example, metacognitive students are more likely to consciously look for relationships in the topics they study, thus influencing their study strategies and ultimately how much they learn.

The development of metacognitive and self-regulatory abilities is essential for enhancing memory of studied materials, especially in active learning environments which depend on volitional monitoring and control. These abilities are heavily dependent upon *executive functioning*: a set of cognitive processes that are necessary for the cognitive control of behavior (Schwartz, 2008). This implies that executive functioning capabilities are prerequisite for effective self-regulation and metacognitive monitoring and control during learning. At present, however, the relationship between executive functioning and the efficacy of active learning is largely unexplored, including whether populations of students with impairments in EF may differ in learning outcomes.

Attention deficit hyperactivity disorder (ADHD) is a prevalent developmental disorder characterized by inattention or hyperactivity/impulsivity. Individuals with ADHD typically experience impairment in executive functioning and academic outcomes. A large proportion of individuals exhibiting ADHD symptoms in childhood continue to have symptoms and associated impairments into adulthood (Barkley, Fischer, Smallish, & Fletcher, 2002; Barkley, Murphy, & Fischer, 2008). These adults are less likely to consistently use effective study strategies, have lower grade point averages (GPA), and more academic difficulties (Barkley, Murphy, & Fischer, 2008). For adults with ADHD who attempt college, where much learning is student-centered, impairment in executive functioning may fuel difficulties with metacognitive and self-regulatory processes and ultimately play a role in academic impairments. However, few studies in young adults with ADHD have gone beyond measures of academic performance to examine what these individuals are actually doing, or not doing, when they attempt to guide their own learning. Further, despite such academic impairments, few studies have focused on interventions for college students with ADHD or the effectiveness of specific learning strategies in this population.

In this study I explore the impacts of guided metacognitive monitoring during learning on study decisions within an experimental active learning paradigm. I investigate the differential impact of metacognitive monitoring on memory between individuals with varying executive functioning abilities, including individuals with or without ADHD. Broadly, our goals are to determine if adults with ADHD indeed suffer in performance, relative to non-diagnosed peers, when given control over their learning and whether the incorporation of cued monitoring judgments influences study choice effectiveness and subsequent memory performance. Cued monitoring judgments should improve performance among those with ADHD, ultimately creating more effective learning strategies and extending the benefits of active learning conditions to individuals with varying executive functioning abilities.

1.1 Metacognitive Model of Self-Regulated Learning

The study of the self-regulation processes involved in study skills and habits was described by Nelson and Narens (1990). They developed the metacognitive model of self-regulated learning. They proposed that successful self-regulated learning requires the learner to (1) evaluate their own awareness of what has already been learned and (2) select and execute effective strategies based on the materials needed to be learned. These two processes are monitoring (evaluating if information has been adequately learned) and control (selecting, initiating, and completing study behaviors). Monitoring is a key process since it is necessary for effective control: one must know what has been learned in order to decide how they will allocate time and then carry out those intentions ("monitoring affects control" hypothesis; Nelson & Leonesio, 1988).

In experimental studies of metacognition, monitoring is often measured by asking learners to make explicit assessments of their level of learning via Judgments of Learning (JOL). These judgments are made, at varying time intervals, after a participant has been given the opportunity to learn one or more item(s). For example, a participant is asked to study a set of paired associates (e.g., *dog – spoon*). After studying each pair, the participant predicts the likelihood of recalling the correct response (e.g., spoon) when later shown the cue (i.e., dog –?) on a scale of 0 – 100 (e.g., "How likely will you recall this accurately later on?"). Memory performance accuracy can then be compared with the JOL's in order to determine monitoring accuracy.

The incorporation of JOL's can provide useful insight beyond the measurement of monitoring accuracy; the ratings could be a reasonable proxy for the current learning state and be compared to subsequent control of learning decisions. Essentially, if a learner can differentiate between items that have been sufficiently learned versus those that have not, then this information can be used to determine which items need to be restudied (Son & Metcalfe, 2005; Finley, Tullis, & Benjamin, 2010). In a meta-analysis of research examining the relationship between JOLs and study time allocation, Son and Metcalfe (2000) found that a majority of the published papers revealed a negative correlation: when given the option of re-studying a portion of previously studied materials, learners typically choose to re-study those items to which they gave the lowest JOLs.

Previous research also shows that learners tend to make reasonable decisions about which items they should re-study. For example, Kornell and Metcalfe (2006) gave learners a list of general facts to study. Learners then decided which half of the items they needed to re-study. These decisions were either honored (they re-studied items they had selected) or dishonored (learners were forced to re-study items they did not choose). Honoring choices about which items to re-study led to greater final test performance than dishonoring their choices. This demonstrates that learners can indeed make effective decisions about which items to re-study and giving them control over their study choices, as is done in active learning environments, can improve memory performance. This collective evidence suggests that learners control their studying based on the results of their monitoring (i.e., JOL ratings), generally making wise choices about what to re-study and spending more time on items they have judged most difficult to remember. Perhaps then, the inclusion of JOL's prompts engagement in the individuals' necessary metacognitive processes (i.e., monitoring of their current memory) and has the potential to assist in guiding learners' control over study decisions.

1.2 Metacognition and Executive Functioning

Given that metacognitive monitoring and control processes involve the updating and monitoring of information, their effectiveness should depend on learners' ability to construct effective strategies and ignore goal-irrelevant information. The ability to monitor effective strategies and direct attention to relevant information relies heavily on one's executive functioning (Barkley, 2012) and previous research has shown that individuals differ in their ability to implement various executive functions (Matthews, Gruszka, & Szymura, 2010; Kane & Engle, 2002). Executive functions are a set of cognitive skills that enable planning, managing, and organizing thoughts, actions, and emotions. It includes three main components: cognitive flexibility (e.g., being able to think about something in more than one way), inhibitory control (e.g., being able to ignore distractions), and working memory (Barkley, 2012). Working memory is important for reasoning and the guidance of decision-making and behavior. This cognitive system has a limited capacity (WMC) that is responsible for temporarily holding information available for processing.

Working memory may be especially important when inferential reasoning (i.e., the integration of information in a relational learning context) is necessary as opposed to simple associative learning, which has been the primary paradigm utilized in past research on metacognition (Brunamonti et al., 2016). In a recent study, Markant (in press) found that the benefits of active control over study choices in a relational learning task depended strongly on individuals' WMC. This study used a novel transitive inference (TI) task where participants learned about the hierarchical organization of a fictional company. The goal was to learn the "chain of command" via premise pairs (e.g., person A > person B, person B > person C) and integrate relational knowledge across the presented pairs (e.g., person A ? person C). Participants were either given control over their study choices (active condition) or were passively presented the pairs for study (passive condition). Control over the selection of premise pairs improved performance relative to passive study in both an immediate test and a retest one week later. However, active control did not benefit all learners: WMC strongly predicted accuracy in the active condition. Therefore, individuals with lower executive functioning abilities (i.e., low working memory capacity) may not be able to succeed in active learning environments where they are engaging in self-regulated learning.

This study did not involve any explicit judgments of learning; however, it would be beneficial to understand whether or not the limitations experienced by those with lower WMC are influenced by the effectiveness of monitoring and control. If participants were guided through the process of metacognitive monitoring (via JOLs), individuals with low WMC may be able to benefit from the opportunity to select study choices independently. This is supported by the monitoring affects control hypothesis (Nelson & Leonesio, 1988): if the participants are prompted to enact effective monitoring during study, then their subsequent learning decisions should be positively affected, resulting in more effective control and ultimately improved performance in active learning environments.

1.3 Monitoring and Control in ADHD

Monitoring of working memory representations is crucial for adding new information related to the current goal and focusing attention on less well-learned information. For individuals with ADHD, breakdowns could occur in monitoring processes, control processes, or both. If adults with ADHD are less accurate at monitoring what has been learned, this would limit their ability to change their behavior strategically. Even if adults with ADHD are capable of accurate monitoring, they may still have impairments in controlling learning by changing, maintaining, or terminating strategies.

Prominent theories of ADHD identify deficits in higher order cognitive processes that impact self-regulation during active learning. Barkley (1997) proposed behavioral inhibition deficits as the core feature of ADHD, yielding downstream difficulties with working memory, emotion regulation, and abstract thinking. Deficient behavioral inhibition might manifest as impulsive responding during a learning task, where the learner utilizes simple learning strategies (e.g., rote repetition) without stopping to monitor the state of items in memory or to consider optimal strategies for a particular set of items. Rapport, Alderson, Kofler, Sarver, Bolden, and Sims (2008) have provided evidence that locates the core deficit in ADHD in the central executive component of working memory. This theoretical formulation would also have consequences for self-regulated learning, as adults with ADHD might have more difficulty holding learning goals “in mind” and coordinating monitoring and study across multiple items. In both models, working memory and/or inhibition are posited to play pivotal roles in the manifestation of ADHD symptoms. Thus, both theoretical and empirical perspectives support the investigation of ADHD within the metacognitive and active learning frameworks.

Impaired metacognitive control of study in ADHD may account for observed problems with encoding of memory. For instance, in a recent meta-analysis, Skodznik, Holling, and Pedersen (2017) found that observed memory deficits in adults with ADHD are actually learning deficits where the impaired performance results from problems at the stage of encoding and not necessarily from deficient storage or retrieval of the information. Specifically, performance differences on memory acquisition trials had a highly significant impact on the performance differences on recall trials and there was no indication of hampered retrieval processes. Several studies of adults with ADHD have examined differences in memory encoding across various experimental tasks. A commonly examined memory paradigm includes paired associate (PA) tasks, which is used to understand how people encode and retrieve newly formed associations among stimuli. Some studies have shown that individuals with ADHD perform more poorly on these tasks compared to non-diagnosed control groups (Knouse, Paradise, & Dunlosky, 2006; Knouse, Anastopoulos, & Dunlosky, 2012) and other research has provided evidence that performance on this task is modulated by participants' working memory capacity (Tse & Pu, 2012; Agarwal, Finley, Rose, & Roediger, 2017).

Further work supports the idea that learning deficits in ADHD are also observed in circumstances that require higher level encoding strategies. Encoding strategies have also been examined with the California Verbal Learning Task (CVLT; Delis, Kramer, Kaplan, Ober, & Fridlund, 1983) which requires participants to learn a 16-item list over five trials. The items are designed to fall into four categories of 4 items each, therefore scores indicating the use of semantic organization or clustering (an effective learning strategy for this task) can be extracted. Holdnack, Moberg, Arnold, Gur, and Gur (1995) found that adults with ADHD had lower semantic clustering scores overall and recall deficits on the final learning trial. Seidman, Biederman, Weber, Hatch, and Faraone (1998) replicated these results and found significantly less clustering for adults with ADHD across all learning and recall trials. Brunamonti and colleagues (2016) examined memory encoding strategies during a TI task in a group of children diagnosed with ADHD. This was the first study to expand this relational reasoning paradigm to this population of individuals. Results indicated that children with ADHD had difficulties in solving TI trials including novel pairs, and that this difference was modulated by individuals' working memory capacity. The authors postulate that these individuals were depending on compensatory encoding strategies that were less effective at improving memory performance. Consistent with this idea, Castel, Lee, Humphreys, and Moore (2011) found that children with ADHD were less efficient at strategically deploying selective encoding during learning. Together, these findings support the hypothesis that self-regulative abilities during the encoding process influence memory performance in those with ADHD.

Knouse, Anastopoulos, and Dunlosky (2012) utilized a task design that was meant to be representative of situations encountered in academic settings (e.g., studying foreign language vocabulary) and found that adults with ADHD were less likely to use self-testing (a powerful strategy associated with enhanced encoding). Specifically, they found that individuals with ADHD were less likely to spontaneously monitor their memory in the absence of overt prompts (e.g., JOL's). These collective findings are critical from both a theoretical and applied perspective because they demonstrate that adults with ADHD may not suffer from an inability to encode new memories, instead, they are failing to consistently and accurately monitor their own learning. Thus, they are unable to perform adaptive learning strategies and control their behavior in the situation at the time that it would be most effective. This concept is also emphasized in Barkley's (1997) theory of ADHD and self-control.

It is important to note that previous research exploring differences in encoding strategies within this population have not yet considered designs including active learning conditions. Given that successful memory performance in active learning conditions depends on effective self-regulated encoding strategies during learning, it is reasonable to hypothesize that metacognitive deficits may influence the strategic use of executive function resources and ultimately yield performance impairment for adults with ADHD in academic settings. The present study examines the inclusion of JOLs in order to prompt metacognitive monitoring and subsequent control designed to assist and strengthen encoding processes as an avenue for ameliorating the memory performance deficits of ADHD in active learning conditions.

1.4 The Present Study

The goal of the current study was to determine if the inclusion of JOLs increases monitoring and influences participants' control of study choices and thus long-term retention of learned material. The act of retrieving information from memory (in this case, via the incorporation of JOLs) promotes the ability to recall material again in the future. Agarwal and colleagues (2017) showed that the incorporation of retrieval practice (use of multiple trials where the participants are retrieving information from memory) yielded a greater benefit for students with lower working memory capacity. In the present study, the inclusion of immediate JOL ratings in each trial engages this retrieval practice and aims to promote monitoring accuracy.

The present study utilizes the JOL design by inserting prompts during study in the memory task. In theory, this design would guide the metacognitive process of monitoring current learning, influence control over informed study decisions in active learning conditions, and ultimately improve memory performance at test while ameliorating performance deficits for those with ADHD. The current study utilizes a novel variation to a transitive inference (TI) task with a passive learning condition and two active learning conditions (active, active+JOL). To allow for a within-subjects comparison of memory performance, each participant completes all three conditions. I hypothesized that: (1) active learning will have differential effects on performance dependent on ADHD diagnostic status where individuals without a diagnosis will benefit from the active learning condition (i.e., performance will be better than the passive condition) while individuals with ADHD will not show a benefit from active control, (2) individuals in the ADHD group will benefit from the condition that includes JOLs during study, these prompts will ameliorate the performance deficit when given active control, (3) the inclusion of JOLs will lead to more effective restudy decisions (i.e., choosing to restudy an item that was judged as less confident) and ultimately yield more accurate performance compared to conditions excluding them. Measures of WMC and response inhibition were also collected in order to test for differences between low and high EF participants and their effects on test performance and metacognitive self-regulation.

CHAPTER 2: METHODS

The following procedures were approved by the university ethical review board (IRB Protocol #18-0441). Recruitment was completed at the University of North Carolina at Charlotte through email announcements reaching the entire student body. Those interested completed an online prescreening questionnaire and those eligible were contacted for scheduling. Research assistants overseeing behavioral data collection were blind to data collected through the prescreening questionnaire and thus unaware of participants' ADHD status. Participants received research participation credit and/or a monetary reimbursement for their participation.

2.1 Screening Procedure

Eligibility was assessed through an online prescreening questionnaire. Individuals who: self-reported a current diagnosis of ADHD and obtained a score above the clinical threshold on the Barkley Adult ADHD Rating Scale (BAARS; Barkley, 2011) were considered eligible and placed in the ADHD group. To determine clinical threshold, a total ADHD score was calculated and matched to associated percentiles. Barkley (2011) states that those scoring at or above the 84^{th} percentile (e.g., BAARS total score of 34) are at least somewhat symptomatic, therefore a cutoff at the 84^{th} percentile was utilized in the criteria. The healthy control group consisted of individuals who self-reported: no history of ADHD diagnosis and obtained a score below clinical threshold on the BAARS. These criteria were selected in order to ensure obtainment of differentiated groups: the ADHD group with confirmed clinical threshold symptomatology and a control group that does not report ADHD symptomatology meeting clinical threshold.

2.2 Procedures

Participants completed two sessions separated by a 6 to 8-day delay. After completing the scheduling process, they were sent a link to an online survey to complete before their first session. This survey is administered in advance in order to minimize session duration and contains questions regarding demographics, comorbidities, frequency of anxiety and depression symptoms, and medication use.

Upon arrival of their first session, a graduate student or trained undergraduate research assistant (blind to ADHD status) obtained informed consent from the participants. Participants then completed the learning task and two executive function assessments. Afterwards, participants filled out a short questionnaire assessing current mood (PANAS) and recency of stimulant medication use. The second session was comprised of the test phases from the learning task. In addition, participants again completed the PANAS and reported whether they had taken stimulant medication on the day of testing. The inclusion of questionnaire measures was exploratory and these variables were not considered in the following analyses.

2.3 Participants

A total of 358 individuals completed the prescreening questionnaire. Several individuals self-reported a diagnosis of ADHD, however they scored below clinical threshold on the BAARS and were excluded (N= 57). Similarly, 23 individuals who did not report a diagnosis of ADHD obtained too high of a score on the BAARS and were excluded. 77.6% of the respondents were found eligible based on the screening criteria and were invited to begin the scheduling process (ADHD group: N = 36, BAARS M = 40.92, SD = 8.1; Control group: N = 242, BAARS M = 12.01, SD = 8.73).

A total of 89 participants completed the first session, however 3 had incomplete task data and were removed for the following analyses. The final sample consisted of 86 participants (*M* age = 22.5, *SD* = 5.69; 63% female; 37.21% white; 24.42% Asian; 8.14% Hispanic/Latino; 22.09% African American; 6.97% Other). The ADHD group consisted of 14 individuals, yielding a total control group sample of 71 participants. Sixty participants returned one week later for their second session (31.8% attrition). A power analysis was performed using the data from Markant (in press) and the current sample size (N=86) and task design using the simr R library (Green & MacLeod, 2015). This indicated that the present design was estimated to have 82% power to detect a comparable within-subjects difference between study conditions (change in relative odds = .16) and 86% power to detect a subject-level effect of working memory or response inhibition (change in relative odds = .30).

2.4 Learning task

The transitive inference (TI) learning task involved a within-subjects manipulation of study condition: passive (no control over item selection), active (control over item selection), and active+JOL (control over item selection with judgments of learning). Participants were instructed to learn the relative ranking of employees within three different corporate hierarchies by studying pictures of faces. In the active condition, participants chose which item to learn about on each trial, followed by the presentation of the item that is immediately higher in the hierarchy (i.e., the selected person's "supervisor"). In the passive condition, participants observed a predetermined, pseudorandom training sequence. In the active+JOL condition they were given control over study choices as in the active condition, but they were also asked to make JOLs regarding their current memory immediately prior to their selection. In order to reduce interference across conditions, image background color varied for each round (i.e., face images within each corporate hierarchy had a different background color; either red, blue, or yellow).

The test phase was comprised of cued recall trials (e.g., identify the direct supervisor of a given employee) as well as inference trials (e.g., given two faces, choose the person who is higher in the corporate hierarchy). Importantly, in inference trials participants were asked to infer the relative rank of non-adjacent persons in the hierarchy, requiring them to integrate across multiple studied associations to answer correctly. In the test phase, participants also made JOL's (i.e., "How confident are you that you know who is ranked higher?") before they made their final response.

2.5 Metacognitive Judgments

Learning Phase JOLs. Participants were asked to make judgments of current learning in the active+JOL condition of the TI learning task (Figure 2, top). Before they made their study choice selection, participants were asked, for each cue: "How confident are you that you know the direct supervisor of this person?" and made a rating on a 0% – 100% scale from 0%: not at all confident to 100%: extremely confident. This rating functions as a prompted self-regulatory strategy and should promote metacognitive monitoring and control during learning. This rating is also compared to study choices to determine if their monitoring is indeed influencing their control.

Test Phase JOLs. Participants were also asked to make judgments of learning at test phase, in all conditions of each task, before making their final response (Figure 2, bottom). They were asked: "How confident are you that you know who is ranked higher?” on a 0% – 100% scale from 0%: not at all confident to 100%: extremely confident. This judgment is compared to actual performance in order to obtain a measure of monitoring accuracy.

2.6 Executive function assessments

Response inhibition: Stop signal reaction time task (SSRT). In the SSRT (Verbruggen et al, 2008), participants learn to press 1 of 2 keys according to the direction of an arrow presented on screen. On a subset of trials, a stop signal (an auditory tone) occurs after the arrow is presented. Participants are instructed to inhibit their response whenever the stop signal occurs. The delay between stimulus and stop signal is varied across trials in order to estimate the stop signal reaction time (SSRT), the amount of time it takes for participants to inhibit a trained response (Alderson, Rapport, & Kofler, 2007). A larger SSRT indicates poorer response inhibition.

Working memory capacity: Operation span (ospan). The operation span is a well-established measure of working memory capacity in which participants attempt to hold a sequence of items in memory while evaluating a set of math operations (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005). In the task, participants complete a set of trials in which they report the accuracy of a simple math equation (e.g., "Is (4/2)-1=1 ?"), which is followed by a letter that they are instructed to hold in memory. After multiple items are presented, they are then asked to recall as many letters as possible in the order in which they appeared. Operation span is scored based on the total number of items from trials in which the entire set was recalled in the correct order.

CHAPTER 3: RESULTS

The final sample consisted of 86 participants with 14 in the ADHD group and 71 in the healthy control (HC) group. Given the small size of the ADHD group, in the following analyses I first examined the relationships between executive functioning and task performance using the combined dataset (with a median split on SSRT and operation span, following Markant, in press). In addition, I conducted exploratory analyses testing differences in performance between HC and ADHD groups and by condition within the ADHD group.

3.1 Executive Functioning

Working memory capacity. Participants were accurate at evaluating the validity of the math operations (proportion of errors $M = 0.03$, $SD = 0.04$) on the operation span task, suggesting that participants exerted reliable effort. Operation span was scored according to the summed number of letters recalled in the correct order, for those trials in which no errors were made, where higher scores indicate a larger WMC ($M = 43.07$, $SD = 17.23$, median = 44). Operation span scores were standardized prior to inclusion in the regression models described below. A median split on operation span was used to divide participants into a low WMC group (N = 39) and high WMC group (N = 47).

Response inhibition. SSRT (the amount of time it takes for participants to inhibit a trained response) was calculated where higher scores indicate poorer response inhibition ($M = 148.97$, $SD = 104.05$, median = 133.67). Although there was no explicit performance criterion for exclusion, I assessed the proportion of times participants failed to respond on trials where there isn't a stop signal (i.e., misses) in order to assess overall performance in the task. The mean proportion of misses was 0.02 ($SD = 0.04$) indicating that participants maintained high performance in the task. A median split on stop signal reaction time was used to divide participants into a low SSRT group (N = 43) and high SSRT group (N = 43).

3.2 Test Performance

Test trial responses were scored according to whether participants correctly identified the superordinate item in each test pair (0 = incorrect, 1 = correct). Test trials involving either endpoint of the hierarchy were excluded since participants could rely on non-transitive strategies to respond (e.g., the highest-ranked item was never presented as an option on the left side of the screen).

Accuracy was modeled using mixed effects logistic regression. Given the repeated measures design (i.e., where multiple observations are related to the same individual), random intercepts were included for participants. The model included fixed effects for condition (active/active+JOL/passive), session (test/retest), trial type (recall/inference), operation span (low/high) and SSRT (low/high), as well as the interaction between session and trial type.

Table 1 presents parameter estimates and confidence intervals for fixed effects in terms of relative odds ratios (OR), which indicate the multiplicative change in the odds of responding correctly given a unit change in the predictor. At the first test, inference performance was significantly lower than recall (*OR* = 0.68, *CI* = [0.58, 0.80], $z = -4.90$, $p < .001$). At the retest, however, inference performance was higher than recall (*OR* = 1.42, *CI* = [1.17, 1.71], $z = 4.37$, $p < 0.001$). Performance declined from test to retest on both recall trials (*OR* = 0.38, *CI* = [0.32, 0.44], $z = -11.80$, $p < 0.001$) and inference trials (*OR* = 0.78, *CI* = [0.64, 0.95], $z = -3.03$, $p = .002$).

Overall, active+JOL performance was significantly higher than active performance (*OR* = 1.23, *CI* = [1.08, 1.41], *z* = 3.12, *p* = .002), but was not significantly different from passive performance (p = .17). Passive performance was not significantly different from active performance (p = .10). Poorer response inhibition, as measured by larger SSRT, was negatively related to overall test performance (see Figure 3; *OR* = 0.66, *CI* = [0.45, 0.97], *z* = - 2.16, *p* = 0.03). Including the interaction between SSRT and condition did not lead to a significant improvement in model fit (χ^2 (2) = 5.39, p = 0.07). In contrast, there was no effect of operation span on test accuracy (p = .63), indicating that WMC was not related to performance in the task.

3.3 Selections during learning

The next analysis focused on participants' selections in the learning phase of the active+JOL condition and their relationship to JOL ratings. Participants gave JOLs (ranging from 0–100) for both options in each trial. For each trial, I calculated the difference between JOL ratings of the selected option and the unselected option. The mean JOL difference score was calculated for each participant to measure their overall tendency to select options they judged to be more or less well-learned. For example, if a participant preferred to select options with lower JOL ratings (i.e., the options judged to be less well learned than the alternatives in the same trials) then their difference score will be negative.

A linear regression was fit to the JOL difference scores with operation span (continuous) and SSRT (continuous) as predictors. There was significant negative effect of operation span on JOL difference score (see Figure 4; β = - .01, *CI* = [-0.03, -0.002], *t* = - 2.31, *p* = .02), but no effect of SSRT (*p* = 0.62). These results indicate that participants with higher WMC were more likely to choose items for study which they previously rated as less well learned, whereas participants with lower WMC were more likely to choose items rated as well learned (see Figure 4). I also considered whether JOL difference scores had an effect on performance. A correlation between JOL difference ratings and test performance in the active+JOL condition yielded a non-significant result (r(84) = -0.01, $p = 0.92$), indicating that the tendency to select less well-learned options for study was not significantly related to test accuracy.

3.4 Test Phase JOLs.

The next analysis focused on the JOL ratings at test in order to evaluate monitoring accuracy. I fit another version of the model that included test JOL in order to see how it is related to accuracy (i.e., a positive effect indicates that as people give a higher JOL it is more likely that they will be correct on that test trial). JOLs were significantly, positively related to accuracy in all three conditions (active: $OR = 2.30$, $z = 11.43$, $p < .001$; passive: $OR = 2.25$, $z = 11.29$, $p < .001$; active+JOL: $OR = 1.97$, $z = 9.36$, $p < .001$), but there were no differences in the magnitude of the effect between conditions. This indicates that participants' monitoring accuracy was effective in all conditions.

Including the interaction between JOLs and SSRT in this model did not lead to a significant improvement in model fit (χ^2 (1) = 3.50, p = 0.06), and neither did the inclusion of the interaction between JOL and operation span (χ^2 (2) = 0.15, p = 0.93). This indicates that the accuracy of metacognitive monitoring was not related to either EF measure.

3.5 Exploratory Analysis of ADHD Performance

In order to test whether ADHD status had an effect on test performance I fit an additional logistic regression model with ADHD status as a predictor, but there was not a significant effect (χ^2 (1) = 2.07, p = .15), potentially due to the small size of the ADHD group. I performed an exploratory follow up analysis focusing on performance within the ADHD group. Test accuracy on non-endpoint trials was modeled using logistic regression with fixed effects for session, trial type, and condition, as well as pairwise interactions between those factors (see Figure 5 for test performance separated by group). Post-hoc contrasts were used to compare performance between study conditions within the ADHD group. Performance was higher in the active+JOL condition than passive condition on inference trials during initial test (*OR* = 1.78, *CI* = [0.90, 3.51], *z* = 2.27, *p* = 0.02), but there were no other significant differences at initial test. At retest, performance was higher on recall trials for the active+JOL condition compared to the active condition (*OR* = 1.77, *CI* = [0.81, 3.87], *z* = 1.97, *p* = 0.05), but was not significantly different from the passive condition (*p* = 0.17). On inference trials in the retest, active+JOL was better than both the active (*OR* = 1.91, *CI* = [0.84, 4.34], *z* = 2.13, *p* = 0.03) and the passive condition (*OR* = 2.06, *CI* = [0.91, 4.64], *z* = 2.39, *p* = 0.02).

CHAPTER 4: DISCUSSION

The goal of the current study was to assess the impact of individual differences on the outcomes of active learning environments where learners are given control over their own learning. Although active control has often been linked to superior learning outcomes, recent work suggests that it may not be effective for learners with poorer executive functioning (Markant, in press). More specifically, the current goal was to assess differences in performance between individuals with and without ADHD on a variation of a common transitive inference paradigm which includes conditions where the learner is given control over their own learning. I predicted that those with ADHD would have lower performance in this condition given the association between ADHD and impairments in executive functioning (Barkley, 1997; Rapport et al., 2008).

Another goal of this study was to determine if the inclusion of JOLs during study increases metacognitive monitoring and influences participants' control of study choices and ultimately, test performance. Specifically, I predicted that individuals in the ADHD group or with poor executive functioning would benefit from JOLs during study, ameliorating the performance deficit when given active control. Further, the inclusion of JOLs during learning were expected to lead to more sensible restudy decisions (i.e., better control) and yield more accurate performance compared to conditions without such metacognitive prompts.

Overall, there was a positive effect of JOLs during study on test accuracy. The inclusion of JOL ratings led to significant improvements in test performance compared to the active condition. These results support the incorporation of JOLs as a promising avenue for modifications to active learning techniques that may be advantageous. Their inclusion imposes an external structure on the metacognitive and self-regulatory processes in environments that require the learner to exert control over their own learning. An important next step would be to assess the generalizability of the positive impact of JOLs in designs that include more complex materials and other more educationally representative learning tasks.

When testing for differences between low and high EF participants, there was a significant effect of response inhibition but not WMC on test performance. In particular, individuals with poorer response inhibition had lower overall performance at test. This result is intriguing given that there were no significant interactions between study condition and SSRT. One may predict poor response inhibition would lead to poorer performance only in those conditions where they are given control over their study, but this was not the case in the current study. It might be that the effect is occurring at retrieval (test phase), rather than at encoding (learning phase) where poor response inhibition causes a higher proportion of error responses across the board. This explanation is also consistent with the null finding that SSRT was not related to JOL difference scores.

Further, there was no effect of WMC on performance. This is surprising given the results of Markant (in press), in which higher WMC participants performed much better in the active condition. Characteristics of task design could explain these results: there was a change in the stimuli (the current study included a 7-person hierarchy compared to the previous 9-person hierarchy) and the total number of trials per condition (decreasing from 72 to 35). Also, the stimulus sets were changed such that each hierarchy had a mix of men and women. This may have made the task easier by enabling the use of other strategies (e.g., a verbal labeling strategy) that place less demands on WMC. These decisions were made in order to decrease duration of participation; however, this may have also inadvertently caused the null findings by making the task easier and ultimately limiting the ability to detect performance deficits among those with lower WMC.

Although WMC was unrelated to test accuracy, individuals with higher WMC were more likely to choose items to study which were rated with lower JOL's (i.e., they chose to study items that they judged as less well learned). The opposite was true for those with lower WMC: they tended to choose items given higher JOL ratings, meaning that they were choosing to study items that they previously rated as already well learned. Despite this positive effect of monitoring on control for high WMC participants, there was no link between choosing less well-known options and subsequent test performance. As noted above, however, there was an overall positive effect of making JOLs on performance. Perhaps then, people with lower WMC, even though they tended to choose to study items with higher JOLs, still benefited from making JOLs compared to active study alone. One reason for this may be that monitoring itself (e.g., having to engage in retrieval practice; Karpicke, 2009) benefits memory, independent of the effects of that monitoring on which items are selected (i.e., subsequent control).

These findings run counter to my prediction that metacognitive judgments during learning would help lower WMC participants to adaptively select items during study. Perhaps the prompted JOLs were not a sufficient mechanism for facilitating effective metacognitive control. Komori (2016) tested how limits in executive functioning, specifically WMC, influenced accuracy of metacognitive monitoring. Results confirmed that WMC affects accuracy of monitoring where participants with high WMC were better able to engage in monitoring using learning judgments compared to low WMC participants. These findings suggest that differences exist in the ability to engage in monitoring during a learning task between individuals with high and low WMC. Additionally, Coutinho and colleagues (2015) found that the act of monitoring uncertainty and acting on it actually places additional demands on working memory. The authors posit that working memory resources play a critical role in uncertainty monitoring; therefore, it is possible that the development of metacognitive capacity relies on the development of working memory. Individuals with sufficient cognitive resources (i.e., higher WMC) may be better able to engage in JOLs and subsequently use them to inform study decisions, while the act of engaging with JOL prompts may place additional demands on already limited resources for those with lower WMC.

The present study was limited by the small number of participants in the ADHD group. I specifically screened with the goal of obtaining two differentiated groups (ADHD/high BAARS and no ADHD/low BAARS), unfortunately this resulted in a very small ADHD sample size. Nevertheless, the results of an exploratory analysis focusing on performance within the ADHD group suggests that learners with ADHD did show the predicted benefit from JOLs during study. In particular, at the retest, the active+JOL condition was associated with better performance than both the active and passive conditions. Although it is important to keep in mind the limited sample size, these results suggest that JOLs during study may be beneficial to performance for individuals with ADHD. Teaching adults with ADHD how and when to use effective judgments as an active self-regulated learning strategy seems an obvious direction for intervention. Interventions that impose an external structure on the process, such as computer programs that prompt JOLs, may be advantageous and useful in a clinical or university disability services setting.

An additional next step would be to generalize strategy effectiveness with more complex materials and to other educationally representative learning tasks. It is important to consider alternative teaching styles or the incorporation of interventions within active learning environments for those with deficits in executive functioning. The use of guided, effective study strategies is a promising avenue, supporting the development of adapted active learning techniques suited for those with lower executive functioning resources.

Table 1

Estimated fixed effects from mixed effects logistic regression model of test accuracy.

Predictor	OR	95% CI-lower	95% CI-upper	Wald *z*	*p*
(Intercept)	7.77	5.45	11.17	11.31	<.001
Condition [active+JOL]	1.24	1.08	1.41	3.12	0.002
Condition [passive]	1.13	0.99	1.28	1.76	0.078
Trial type [inference]	0.68	0.58	0.80	-4.90	<.001
Session [retest]	0.38	0.32	0.44	-11.80	<.001
Session [retest] x Trial type [inference]	2.08	1.67	2.59	6.55	<.001
Operation span [high]	1.10	0.75	1.61	.49	0.626
SSRT [high]	0.66	0.45	0.97	-2.16	0.031

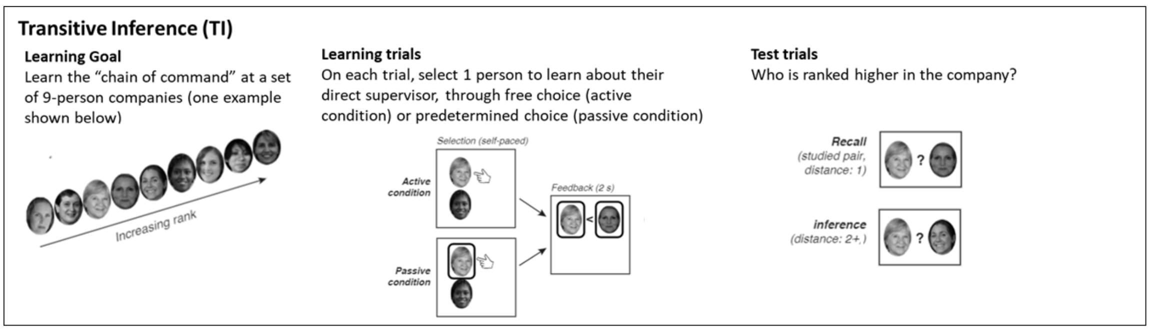

Figure 1. Transitive Inference learning task.

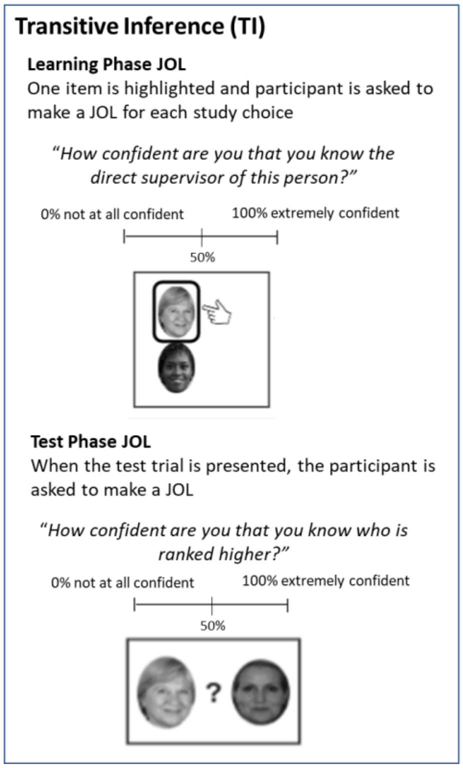

Figure 2. Judgments of learning in the learning phase (top) and test phase (bottom).

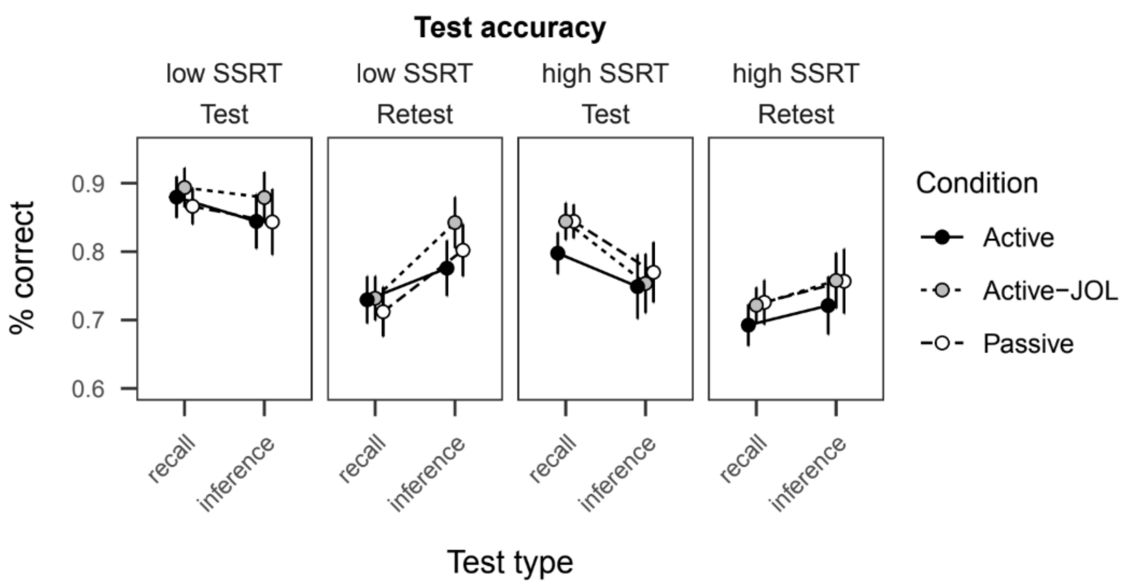

Figure 3. Test accuracy after median split on SSRT, for both the immediate test and delayed retest. Performance is shown as a function of study condition (active/active+JOL/passive) and inferential distance (recall/ inference). Error bars represent within-subjects 95% confidence interval

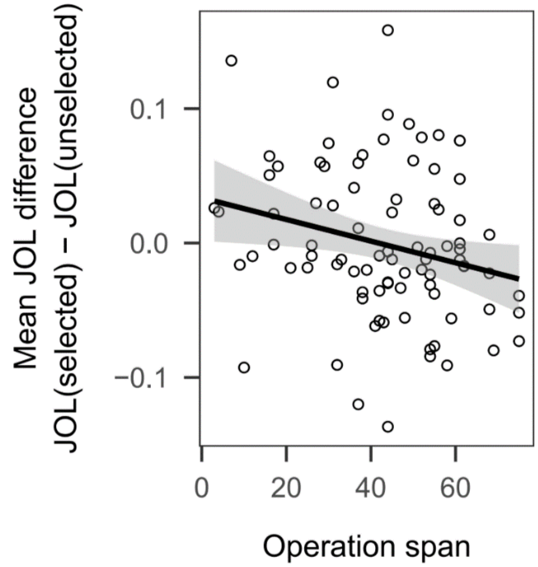

Figure 4. JOL difference scores as a function of operation span. Preference to select options with lower JOL ratings (i.e., the options judged to be less well learned than the alternatives in the same trials) yield negative JOL difference scores.

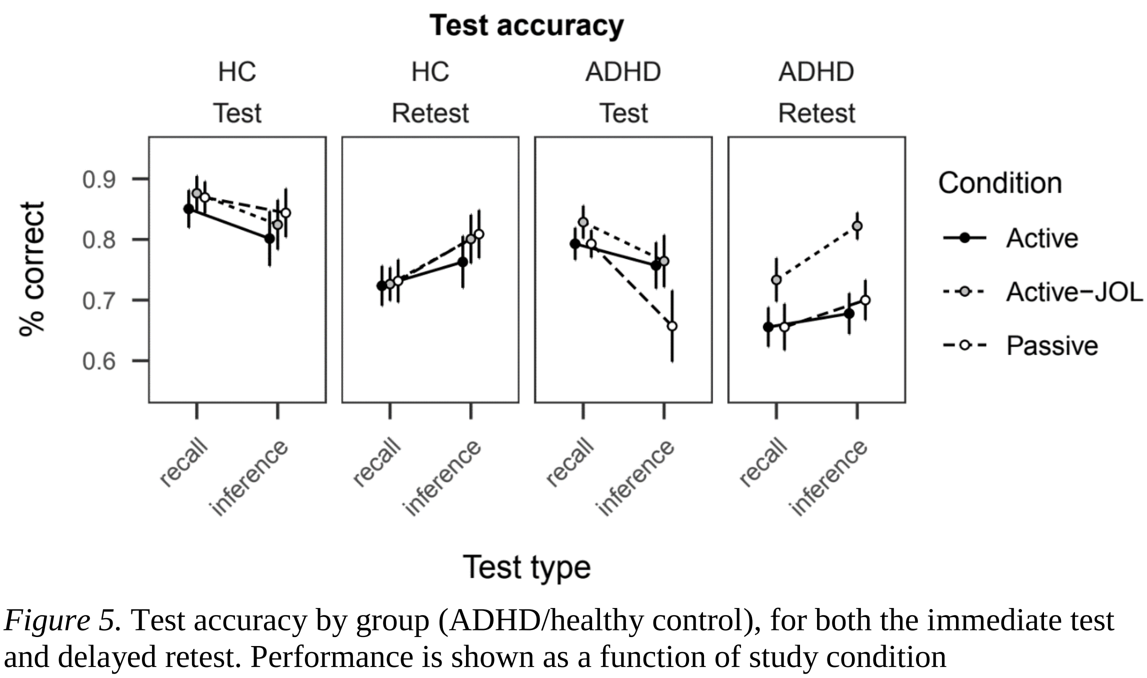

Figure 5. Test accuracy by group (ADHD/healthy control), for both the immediate test and delayed retest. Performance is shown as a function of study condition (active/active+JOL/passive) and inferential distance (recall/inference).

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