Investigating Internal and External Attention Switching in Adults with ADHD

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Abstract

To perform effectively in everyday tasks, the use of attention is crucial to select for the information most relevant to the task at hand and to inhibit irrelevant distractions. When selecting from competing inputs, attention to information from the environment is considered as external attention, whereas attention to information from internal thoughts is considered as internal attention. The ability to maintain attention is also important for task performance, and this ability is reduced in individuals with attention-deficit/hyperactivity disorder (ADHD) due to their frequent tendency to mind wander and produce self-generated thoughts. Since mind wandering is intrinsically driven, ADHD individuals might have a possible deficit in switching from internally focused attention to externally focused attention, resulting in the reduced ability to focus on the task at hand. In this study, we investigated this potential deficit by designing a paradigm to measure the time incurred to switch between the two types of attention. Similar to previous studies, we observed a significant time cost in switching attention between two internal representations. However, we did not find a significant difference in the time cost of switching between internal and external attention. Therefore, we were unable to conclude whether ADHD individuals have a deficit in switching from internal to external attention.

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Introduction:

Internal and External Attention

Imagine sitting in a coffee shop. You might be focused on reading the book you have in your hands, but suddenly, the clanging sound of the coffee bean grinder breaks your focus, and the chatter of other people's conversations dramatically amplifies. You refocus on your book, but your stomach growls, and you find yourself thinking about what to eat for lunch. Not just in a coffee shop, but at any given moment, there is a vast array of information available to the human brain, both from the environment and from our own thoughts. In fact, there is too much information for the brain to process efficiently. Thus, effective performance on a task requires using attention to select for the information most relevant to the task at hand and to inhibit irrelevant distractions, both from within and without.

The type of information that is selected determines which type of attention is being used: internal or external attention. More specifically, internal attention modulates information that is generated in the mind, including long-term memory, representations in working memory, task rules and responses, and decision rules (Chun et al., 2011). Thus, attention largely refers to cognitive control processes. In the coffee shop example, thinking about lunch plans amounts to internal attention about an internal representation. On the other hand, external attention modulates perceptual information obtained through the senses, which includes spatial and temporal information and modality-specific input (Chun et al., 2011). Listening to the coffee machine would be an instance of external attention. Due to the wide availability of information, attention is extremely important in determining how relevant information is processed, how well the task is performed, and memory of the task itself.

To control attention, regions in the prefrontal cortex and posterior parietal cortex are primarily responsible for sending signals to select and process competing bits of information (Buschman & Miller, 2007; Miller & Cohen, 2001; Ridderinkhof et al., 2004). Furthermore, previous studies have demonstrated that internal and external shifts of attention have little (Rushworth, Paus, & Sipila, 2001) to no overlap (Ravizza & Carter, 2008) in neural activation and are instead carried out by domain-specific brain mechanisms. It has been proposed that control of internal attention is facilitated more by frontal regions, while external attention is facilitated more by parietal regions (Nobre et al., 2004). On the other hand, other fMRI studies have shown that there are overlapping brain regions – right medial superior parietal lobule (mSPL), left intraparietal sulcus (IPS), and right superior frontal sulcus (SFS) – involved in shifts within both types of attention, as well as distinct areas of the brain activated for only one type of attentional shift (Tamber-Rosenau et al., 2011). In these three overlapping brain regions, what differs between shifts within internal and external attention is that they evoke different patterns of brain activity within the right SPL, left IPS, and right SFS. Additionally, during the initiation of attentional shift (reconfiguration), subpopulations of neurons within the mSPL were selectively activated for either internal or external attention (Chiu & Yantis, 2009; Tamber-Rosenau et al., 2011).

However, selectively attending to competing inputs of information, either from the external environment or from internally held representations, is only the first step to guide desired behaviors. After selecting for the relevant information, attention must also be maintained over the course of the entire task for good performance. The inability to maintain attention is one of the main symptoms of attention-deficit/hyperactivity disorder (ADHD).

ADHD, Mind Wandering, and Internal Attention

ADHD is a disorder characterized by symptoms of inattention, hyperactivity, and impulsivity. It was previously thought that ADHD was exclusively a childhood disorder; now, it is also accepted as an adult disorder with a prevalence of 1-36% carrying over from a childhood diagnosis (Moss et al., 2007). ADHD symptoms can negatively impact many aspects of an individual's life, especially in the realms of academic performance and social interactions. Therefore, studying underlying mechanisms of ADHD is crucial to determining the most effective treatment.

The ability to hold attention over long periods of time is diminished in individuals with ADHD because they tend to exhibit the behavior of mind wandering. When mind wandering occurs, attention shifts away from the present moment or the task at hand to internally generated content that is generally task unrelated (Giambra, 1989). This attentional shift is called perceptual decoupling, in which attention to external input is reduced and is restructured to instead focus on internal inputs (Schooler & Smallwood, 2015). Therefore, mind wandering is a form of internal attention because these self-generated thoughts come from intrinsic changes within an individual and are not driven by external environmental cues (Schooler & Smallwood, 2015). Self-generated thoughts that occur during mind wandering often encompass personal relevance and time, including thoughts of the past and future (Smallwood & O'Connor, 2011).

Additionally, self-generated thought can be intentional or unintentional, and can be related or unrelated to the task at hand. This ties into the importance of meta-awareness during mind wandering, or whether individuals are aware that they are mind wandering while doing a task. More often, individuals display a lack of awareness and fail to recognize that their mind has drifted away from the task at hand (Schooler, 2002). The degree to which individuals are aware of their mind wandering has been linked to how detrimental mind wandering is to daily life, with unintentional mind wandering being more detrimental (Franklin et al., 2014). Furthermore, individuals who exhibit more ADHD symptoms are more likely to experience detrimental mind wandering (Franklin et al., 2014).

The neural basis behind mind wandering involves the default mode network (DMN), a large core network of regions in the medial prefrontal cortex and the posterior cingulate cortex, along with two subsystems: the medial temporal lobe subsystem and the dorsal medial subsystem. The DMN is active during the resting state (Greicius et al., 2003), but also during the types of thoughts produced with mind wandering: activity in the DMN increases during thoughts of time and place (Addis et al., 2012) and thoughts of oneself (Kelley et al., 2002; Macrae et al., 2004; Mitchell et al., 2006). Furthermore, the DMN exhibits increased activity during task-unrelated self-generated thought, a hallmark of mind wandering (Allen et al., 2013; Christoff et al., 2009; Mason et al., 2007; Stawarczyk et al., 2011). Another interesting facet of the DMN that links this region to internal attention is that increased activity in the medial prefrontal cortex causes a decrease in activity of brain regions used for external sensory processing, such as the occipital cortex (Vincent et al., 2006). In addition, more engagement of mind wandering while reading or at rest enhances this contrast, meaning as activity in the DMN increases, the activity in the occipital cortex is more reduced (Vincent et al., 2006). Since mind wandering is a form of internal attention, internal attention can be partly attributed to activity in the default mode network.

In addition to the DMN showing increased activity with mind wandering thoughts (Christoff et al., 2009), this brain network also exhibits heightened activity during task performance in ADHD individuals due to their reduced ability to suppress the DMN (Peterson et al., 2009). This inability to deactivate the DMN has been linked to momentary lapses in attention during task performance, leading to slower and less accurate responses (Weissman et al., 2006). Similarly, ADHD has also been shown to be associated with increased mind wandering and poor task performance on attentional measures (Shaw & Giambra, 1993). Therefore, a possible hypothesis for why individuals with ADHD have difficulty maintaining external attention to a task is that they get caught-up in mind wandering, leading to an overdrive in the DMN that hinders them from disengaging internal attention. If so, they would have a difficult time switching from their internal thoughts to an external stimulus. This idea leads to the main focus of our study: to investigate whether ADHD patients indeed have a deficit in switching from internal attention to external attention.

Attention Switching in Working Memory

To investigate internal and external attention switching, we first consider switching between two representations held in working memory. Attention to representations in working memory is an example of internal attention because it involves manipulating internal object representations that are no longer externally available (Smith & Jonides, 1999). However, it is well known that working memory is limited in capacity, and it has been proposed that working memory can actively focus attention on only one distinct object or one stream of consciousness at a time (McElree, 2001; Oberauer, 2002). Therefore, in cognitive tasks that require attention to multiple objects at the same time, we must switch between those object representations. This idea of attention switching was explored by Garavan (1998). In his study, Garavan designed a dual-count paradigm to examine features of switching between two objects in working memory.

His self-paced computerized task presented a stream of single geometric shapes, selected from two possible shapes, and he asked subjects to keep mental counts of each shape simultaneously. He analyzed two types of trials: stimulus-switch (SS, shape presented is different than shape on previous trial) and stimulus-no-switch (SNS, shape presented is same as shape on previous trial). Garavan (1998) proposed that if working memory can actively hold only one object representation at a time, it would be easier to update the same count in succession (SNS) than to update two separate counts (SS) because the latter requires internal mechanisms to switch between the shape representations.

The results of his experiment showed that subjects were slower to update two different counts in succession than to update the same count repeatedly, thus supporting the idea that there is a time cost associated with switching internal objects of thought. Reaction time (RT) to an SS figure was slower than RT to an SNS figure by an average of 483 msec, which represents the switching cost (SC). Garavan's findings demonstrated that although we may hold several object representations in working memory, only one item can be active at one time, and it takes time to go from one active item to another. With this in mind, we expanded on the idea of attention switching in Garavan's study by adding another dimension - switching between internal and external representations.

Exploring Internal and External Attention Switching Cost

In our study, we modified Garavan's experiment with the addition of an external component to look at attention switching between internal and external representations. The switching cost found in Garavan's experiment represents the switch cost between two internal representations because subjects internally maintained the counts of both shapes in their working memory. An external component can be added to this task, in which the counts of two additional shapes can be externally displayed on-screen to the subjects, relieving them of the effort to keep count internally. Thus, subjects would have an internal component to maintain the counts of two shapes in their working memory, while also using perceptual attention to track the two externally counted shapes. Consequently, when subjects are presented with an internally counted shape followed by a shape with an on-screen counter, they are switching from internal to external attention. Conversely, if they are presented with a shape that has an on-screen counter, followed by an internally counted shape, they are switching from external to internal attention.

We expanded on Garavan's hypothesis to propose that it may be more difficult for subjects to switch between the two different types of attention (from internal to external, or vise versa) than to switch within each type of attention (between two internally held items, or between two perceptual events). If this is the case, then a switching cost also exists between internal and external shifts in attention. Therefore, we are examining if shifting between the two types of attention incurs a time cost, and if so, determine the switching cost.

Furthermore, our study specifically looks at how this attentional shift applies to adult ADHD subjects. We hypothesized earlier that a possible explanation for ADHD patients' excessive focus on internal attention is due to an overdrive in the default mode network, which is activated during mind wandering. Correspondingly, this heightened activation of the DMN could cause a potential deficit in individuals with ADHD to switch from internal attention to external attention. Thus, we hypothesized that the switching cost from internal to external attention (external switch cost) would be greater in ADHD subjects when compared to control subjects. Another way to examine this potential deficit is to look at the reverse attentional switch, from external to internal. If ADHD subjects are prone to mind wandering, then they would have an easier time to disengage from the external task to focus on their internal thoughts. Therefore, we also hypothesized that the switching cost from external to internal attention (internal switch cost) would be smaller in ADHD subjects when compared to control subjects. We examined internal and external attention switching with a self-paced computerized task modified from Garavan's dual-count paradigm.

Methods:

Subjects

All subjects were University of Michigan undergraduate students drawn from the introductory psychology subject pool and were granted participation credit towards their course requirement. A total of 41 subjects were tested, but due to experimental and data collection errors, only 26 subjects were included in the analyses. All subjects were right-handed. They were separated into two groups: control and ADHD. Subjects were pre-screened to ensure that ADHD participants were previously diagnosed, and control participants had no previous diagnosis, no comorbid disorders, and no stimulant medication use. Each control participant was matched to an ADHD participant of the same gender and age (within two years). Table 1 provides a summary of subject groups' demographics.

Table 1. Demographics of ADHD and Control Subject Groups

	ADHD	Control
Total Subjects	13	13
Number of Males	5	6
Mean Age	19.7 years	19.1 years
Age Range	18-22 years	18-20 years

Measures

Internal-External Task

This was a self-paced E-Prime computerized task designed to measure the time cost of switching between "internal" and "external" stimuli presented to the subject. The task was modified from Garavan's (1998) dual-count paradigm for attention switching by adding an external dimension.

The task required subjects to keep a count of the number of times four different shapes were presented (circle, triangle, diamond, and square). Each shape was assigned to one number on the numeric keypad (1, 3, 7, and 9). Shapes appeared one at a time in the center of the screen, and subjects were instructed to press the number corresponding to the shape with their right index finger to update their count of that shape (i.e. press "7" when a circle appears). Two of the shapes were randomly assigned to external counters, whose counts were displayed on-screen at all times on the left and right side (see Figure 1). The number key corresponding to each external shape was located on the same left or right side of the numeric keypad as the counter displayed on screen. When the key corresponding to an external counter shape was pressed, the appropriate counter on the screen would increase by one. Likewise, two of the shapes were randomly assigned to internal counters. When the key corresponding to an internal counter shape was pressed, subjects were supposed to internally update their count of the shape; there was no external aid to help subjects keep track of the internal counts.

On each trial, a shape would appear in the center of the screen. Subjects would press the corresponding number key to update the counter and would hear a tone indicating that they made a response. After updating the counter, subjects would press "5" to move on to the next trial. If subjects pressed an incorrect corresponding key to a shape and realized the mistake, they were told to proceed as if their previous response had been correct and update the count according to the key they pressed. Figure 1 depicts an example trial sequence, and figure 2 depicts the different trial types in the task.

Figure 1. Trial Sequence of Internal-External Task

Figure 1 demonstrates a trial sequence in the Internal-External Task. Both external counters start at 0. After subjects make a response to an external shape (circle), the counter of that shape was updated on screen. No counters were updated following a response to an internal shape (square).

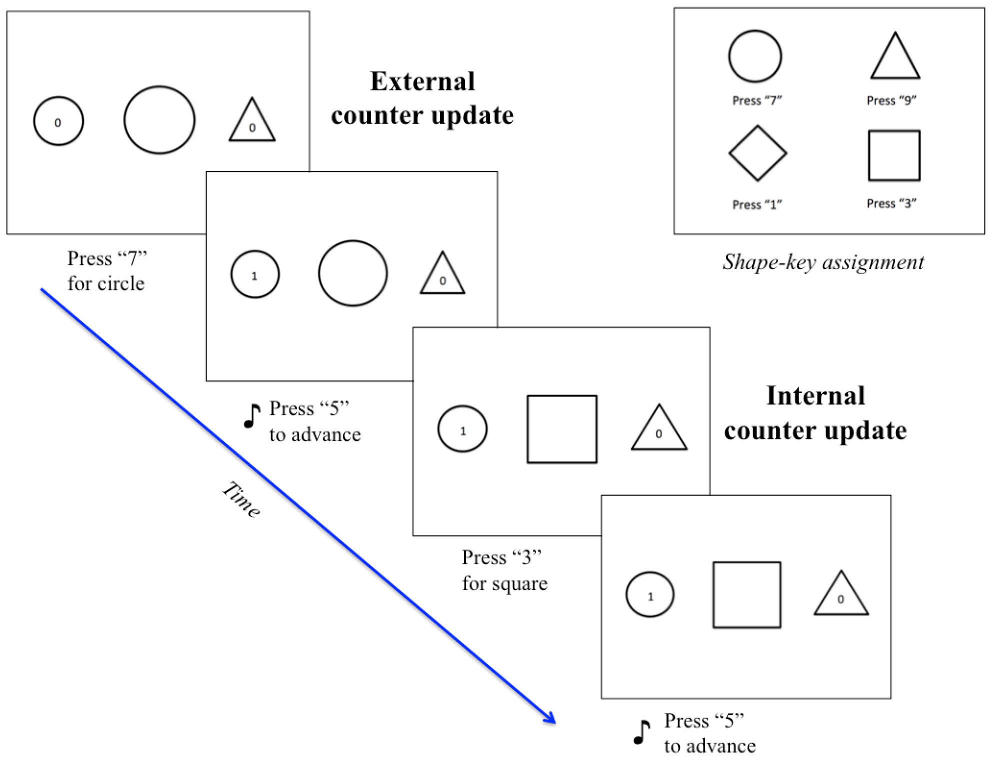

Figure 2. Trial Types of Internal-External Task

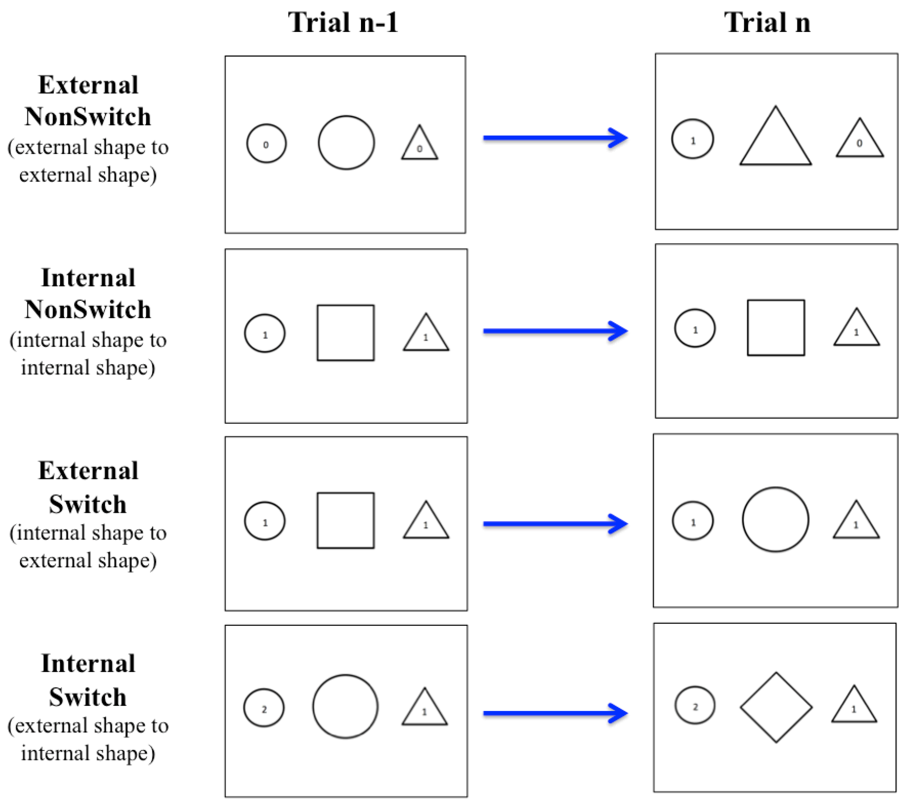

Figure 2 provides examples for the four possible trial types in the task: external NS, internal NS, external switch, and internal switch. Stimulus type (external or internal) refers to shape in the current trial. Thus, in an external switch trial, the current shape is externally counted, and the switch is from an internal shape to an external shape. The same logic can be applied to all four trial types. Since there are two shapes for each stimulus type, in non-switch trials, the current shape could be either of the two shapes from the same stimulus type.

Before the task began, the experimenter explained the instructions to the subject and monitored the subject through 1 or 2 practice rounds. The first practice round consisted of 13 trials, and subjects would only continue to the actual task only if they correctly reported the counts of both internally counted shapes. Otherwise, subjects completed a second round of practice, consisting of 11 trials.

The internal-external task consisted of 369 trials divided into 18 blocks; each block consisted of 16-18 figures or 23-25 figures. It was necessary to vary the number of trials in each block to ensure that subjects could not guess the count of each shape based on the total number of shapes. The length of each block was randomly assigned, and the order of presentation of the shapes was randomly generated. At the end of each block, subjects reported the counts of all four shapes. At the beginning of the following block, the counts of all shapes were reset to zero. Although there were a total of 18 blocks, the first block was considered a warm-up and was excluded from the analyses.

Working Memory Capacity Tasks

Two computer-based measures of working memory capacity were used in this study: Operation Span (Ospan) and Change Detection (Unsworth, Heitz, Schrock, & Engle, 2005; Luck & Vogel, 1997). Both tasks were modified shorted versions that were completed in 10-15 minutes. In Ospan, subjects solved a series of simple arithmetic operations, such as (3+7)-4, and were then presented with a letter following the arithmetic operation. At the end of each block, subjects were required to recall the letters in the order they were presented. In Change Detection, subjects were briefly presented with an array of randomly arranged colored squares, followed by a blank screen. After a short delay, a second presentation of colored squares displayed the same spatial arrangement as the first, but with one square circled. Subjects were instructed to determine if the circled square was the same color as that of the first presentation.

Internal-External Task Exit Questionnaire

This five-question exit survey inquired the counting method used by participants, the level of difficulty they experienced, and whether they followed instructions on responding only with their right index finger. Since the switching cost between different stimuli was on the scale of milliseconds, using only the right index finger controlled for time differences in navigating the number keypad.

Connor's Adult ADHD Rating Scales Self-Report Screening Form (CAARS-S:SV)

The CAARS screening form (short version) was a 30-question assessment of ADHD symptoms according to the criteria outlined in the DSM-IV (Connors, Erhardt, & Sparrow, 1999). Individuals responded to how often each ADHD symptom occurs, ranging from 0 "Not at all, Never" to 3 "Very much, Very Frequently." The final score was reported as a t-score that takes into account both age and gender, and was broken down into 4 subscales: Inattention Symptoms, Hyperactive-Impulsive Symptoms, Total ADHD Symptoms, and ADHD Index.

Cognitive Failures Questionnaire – Memory and Attention Lapses (CFQ-MAL)

The CFQ-MAL was a self-report that assessed memory and attention by measuring how often subjects make minor cognitive errors (i.e. failing to pay attention to someone's name upon first meeting) (McVay & Kane, 2009). It consisted of 40 questions with responses on a 1-5 scale ("never" to "very often"). The scores were summed up, with higher scores indicating a higher frequency of cognitive failures.

Intrinsic Motivation Inventory - Abbreviated Version (IMI-Abbrev)

The IMI-abbrev was a self-report that assessed an individual's intrinsic motivation while completing the Internal-External task. The assessment was modified from the original IMI (Ryan, 1982) to include 2 categories – Interest/Enjoyment and Perceived Competence – as well as an additional question about general motivation to do the task. The questionnaire consisted of 11 questions, and subjects responded to each question on a scale of 1-7.

Semi-Structured Clinical Interview

The semi-structured clinical interview was based off the DSM-V criteria for ADHD diagnosis. A trained experimenter interviewed subjects (both control and ADHD groups) on their symptoms in three categories: Inattention, Hyperactivity, and Impulsivity. In addition, subjects were inquired about the time and circumstances of their ADHD diagnosis (if any), current medications, family history of ADHD, and educational and occupational issues due to inattention. Based on the interview, the experimenter confirmed whether a subject fits the assigned control or ADHD subject group.

Procedure

The one-session study lasted approximately 1.5 hours. It consisted of 3 computerized tasks, paper and pencil questionnaires, and a semi-structured clinical interview. The participant completed the tasks in the following order: CAARS-SV, Internal-External Task (response keys counterbalanced between subjects), Internal-External Task Exit Questionnaire, IMI-abbrev, Ospan and Visual Arrays (order of working memory capacity tasks counterbalanced between subjects), CFQ-MAL, and Semi-Structured Clinical Interview. For the Internal-External task counterbalance, half of the subjects completed the task with numbers 1 and 3 assigned to external counters, while half of the subjects completed the task with numbers 7 and 9 assigned to external counters.

Some participants were unable to complete all measure due to time constraints. In this event, some pencil and paper questionnaires towards the end of the session were omitted to make time for the semi-structured clinical interview.

Results:

For the purposes of this thesis, the section will mainly focus on the results of the Internal-External Task. In the CAARS-SV questionnaire, ADHD subjects on average scored higher than control subjects in all t-score subscales, indicating they experience a higher frequency of ADHD symptoms. The results of other measures will be analyzed in future versions of this study, and the working memory capacity measures will be closely examined to determine how working memory capacity affects internal and external attention switching.

Error Analysis

Subjects were required to report the counts of all four shapes at the end of each block for all 18 blocks of the Internal-External Task. A count was considered accurate if it was within one from the correct number (i.e. if correct count was 5, reported counts of 4, 5, and 6 would be accurate). Subjects with internal count accuracy below 60% were excluded from all analyses, resulting in a total of 13 subjects analyzed in each group. The data were broken down across internal representations and external representations for both ADHD and control subject groups. To examine the accuracy results between the two types of representations, we ran a 2x2 repeated-measures ANOVA on accuracy, with stimulus type (internal shape; external shape) as the within-subjects variable and group (ADHD; control) as the between-subjects variable.

In general, both groups exhibited high count accuracy, with control subjects ($M = 0.932$, $SD = 0.014$) having slightly higher overall accuracy than ADHD subjects ($M = 0.898$, $SD = 0.027$). However, the effect between the two subject groups was not significant, $F(1,24) = 1.232$, $p = 0.278$. External counts were marginally more accurate compared to internal counts, $F(1,24) = 3.465$, $p = 0.075$ (see Figure 3). Since updating internal counters involved the use of working memory whereas external counters were automatically updated on the screen, it makes sense for the external counts to be more accurate than the internal counts. Additionally, there was no significant interaction between count accuracy of each stimulus type and group, $F(1,24) = 0.135$, $p = 0.716$.

Figure 3. Reported Count Accuracy for Internal vs. External Shapes

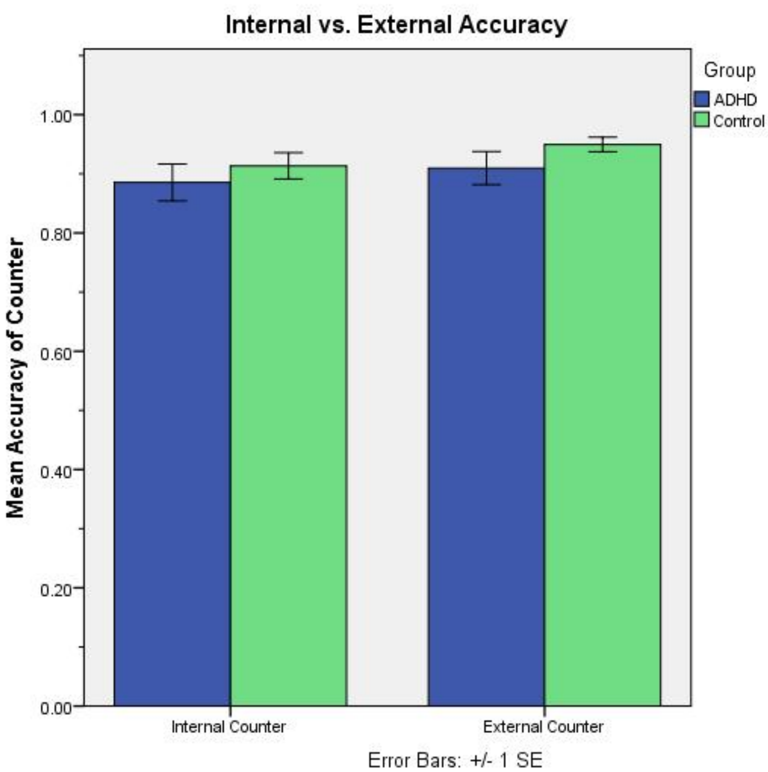

Figure 3 depicts the accuracy of the reported counts of internal and external shapes in ADHD and control subjects. Both groups demonstrated high accuracy in both internal and external counts, with counts of external shapes marginally more accurate than counts of internal shapes. Furthermore, control subjects exhibited higher count accuracy than ADHD subjects for both internal and external stimuli.

Reaction Time (RT) Analysis within Internal Representations

This analysis eliminated the external component of the task and tested the effect of switching between two internal counters held within working memory to determine whether this study had replicated Garavan's (1998) results. Once again, we ran a 2x2 repeated-measures

ANOVA on reaction time, with trial type (switch; non-switch) as the within-subjects variable and group (ADHD; control) as the between-subjects variable.

Similar to Garavan's results, subjects were significantly slower to respond to stimulus-switch (SS) trials compared to stimulus-non-switch (SNS) trials, $F(1,24) = 58.654$, $p < 0.001$. Importantly, there was a significant interaction between group and trial type such that ADHD subjects were more affected by switching between two internal representations than control subjects, $F(1,24) = 4.437$, $p < 0.05$ (see Figure 4). In fact, the switch cost for ADHD subjects ($M = 818$ ms) was almost double the switch cost for control subjects ($M = 465$ ms). Note that the switch cost here is between two internal representations and is not the same measure as the internal switch cost discussed in the next section. Our results were consistent with Garavan's results that maintaining multiple object representations in working memory incurs a switch cost.

Figure 4. Reaction Time of Switch/Non-Switch between Internal Representations

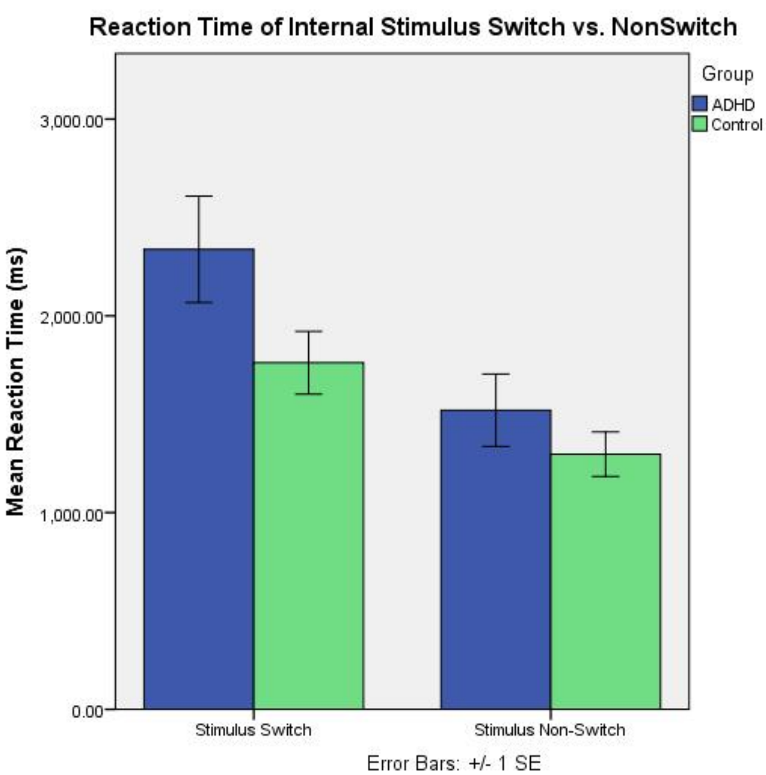

Figure 4 displays mean reaction times of updating the same internal counter (SNS) compared to updating the other internal counter (SS). Subjects were slower to respond to stimulus-switch trials than to stimulus-non-switch trials, and this effect was more pronounced in ADHD subjects.

RT Analysis between Internal and External Representations

To observe the effect of switching between internal and external attention, we determined the average internal and external switch costs (SCs) by taking the difference between the mean internal/external switch RT and the mean internal/external non-switch RT (refer to Figure 2 for clarification of trial types). Since RTs were recorded on a trial-by-trial basis, only trials in which subjects updated the correct shape counter were analyzed to ensure the RTs corresponded to the correct attentional switch. Similar to the error analysis, the data were broken down across internal SC and external SC for both ADHD and control subject groups. A 2x2 repeated-measures ANOVA on switch cost was performed, with stimulus type RT (internal count RT; external count RT) as the within-subjects variable and group (ADHD; control) as the between-subjects variable.

Subjects did not exhibit a significant difference between internal and external switching costs, $F(1,24) = 1.067$, $p = 0.312$. ADHD subjects generally had greater switch costs compared to control subjects, but this effect was not significant, $F(1,24) = 1.751$, $p = 0.198$. There was also no significant interaction between stimulus type and group, $F(1, 24) = 2.733$, $p = 0.111$. Figure 5 provides a summary of the switch cost results for each subject group.

Figure 5. Internal vs. External Switch Cost for ADHD and Control Subject Groups

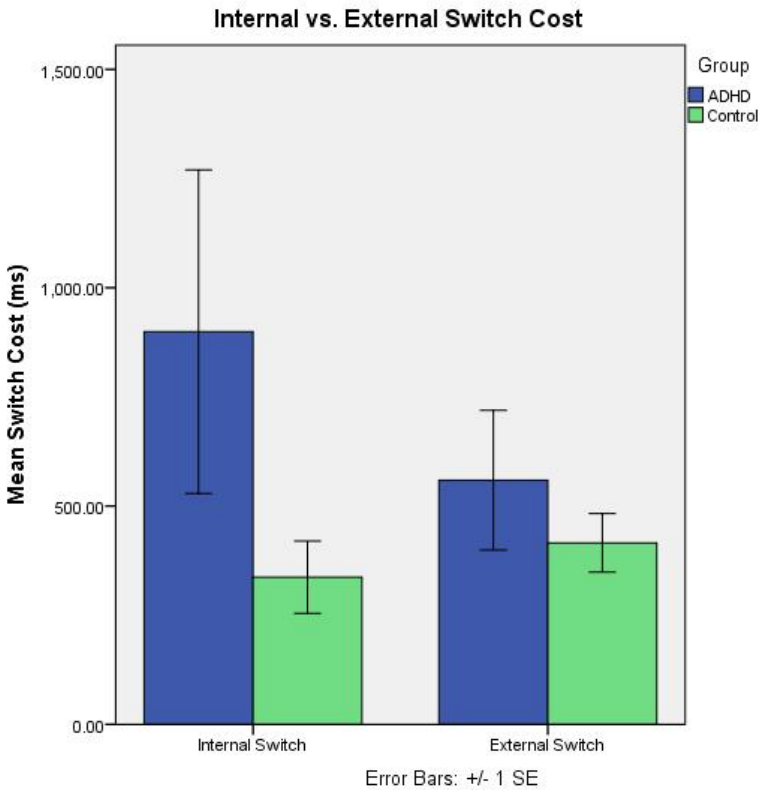

Figure 5 exhibits the internal and external switch costs for both subject groups. ADHD subjects had higher internal and external switch cost than controls, meaning they were overall slower at making an attentional switch. Furthermore, ADHD subjects had a higher internal switch cost than external switch cost, while the opposite effect was observed in control subjects.

We previously hypothesized that since ADHD is associated with increased mind wandering, which is linked to higher DMN activity, ADHD subjects in comparison to controls should either have a higher external switch cost or a lower internal switch cost, both of which favor staying internally focused. Our results, however, indicated that ADHD subjects spent more time in general to do any type of attentional switch between internal and external representations. Overall, these results do not support our hypothesis that individuals with ADHD have a potential deficit in switching from internal to external attention.

Discussion:

This thesis investigated the differences in internal and external attention switch costs between ADHD and control participants by using a self-paced counting paradigm modeled off Garavan's 1998 study. Our hypothesis was that the ADHD group would be more inclined to be internally focused due to an increased activation in the DMN, and thus would exhibit a deficit in switching from internal to external attention. In our analyses, we found the accuracy for internal and external counts to be high for both subject groups, with external counts being slightly more accurate than internal counts. We were able to replicate the results of Garavan's study regarding the existence of a significant switch cost between two internally held representations, which supports previous notions that working memory capacity is limited to only one active representation. However, we did not find a significant difference in the switch costs between internal and external attention, and our hypothesis regarding ADHD subjects having difficulty switching from internal to external attention was not supported by the data.

There are many possible reasons for why the results of this study provided insufficient evidence to support our hypothesis. First of all, the study consisted of a small sample size, with only 13 subjects in each subject group. A small sample size limited the normality, variability, and significance levels of this study, and it did not very accurately represent the whole population of ADHD individuals. Moreover, the population pool from which this sample was taken was strictly limited to undergraduate introductory psychology students. The sample was skewed in demographics, such as age and educational level, which also contributed to the misrepresentation of the ADHD population.

One factor that was not controlled for in this study, but could have had an effect on the significance level of attention switching, was whether ADHD subjects took psychostimulant medication on the day of the experiment. Studies have shown that ADHD individuals off medication were inadequate at suppressing DMN activities, whereas ADHD individuals on medication improved suppression of DMN activity to the same level as control subjects (Peterson et al., 2009). Particularly, those on medication improved suppression in the ventral anterior cingulate and posterior cingulate cortex, two areas in the default mode network that are activated during mind wandering (Peterson et al., 2009). Based on the stimulant medication effects, our proposal that ADHD subjects have more difficulty disengaging from internal attention due to overactivity in the DMN would be mitigated in those taking medication while performing the task. Thus, since ADHD subjects on medication have similar DMN suppression levels as control subjects, the effect between internal and external attention switching between the two subject groups could have been reduced. One way to address this issue is to request future ADHD participants to not take stimulant medication 12 hours prior to the study.

Another possible reason for the insignificance between internal and external attention switching was the counting mechanism used by participants. As indicated in the Internal-External Task Exit Questionnaire, many subjects actually internally kept count of all four shapes, even though two counters were displayed on screen (i.e. "Repeat all 4 counters in my head each time while adding one to the appropriate counter.") If this is the case, then all trial types would be internal non-switch, and there would be no switching between internal and external representations, resulting in inconclusive data. To fix this issue, we could rephrase the instructions to clearly convey that subjects should not be mentally counting the two external shapes, or we could consider other feasible tasks to test the switch cost between internal and external attention.

For future developments of this study, the most important step is to increase the sample size as much as possible to obtain a more representative sample of both subject groups. Furthermore, analyses should be done for all other measures, and individual differences in working memory capacity should be considered when analyzing the attentional switch for both subject groups. As already mentioned, some limitations that we could also control are medication use for ADHD participants, and precise instructions to ensure the use of correct counter updating method for internal and external stimuli. With these changes implemented in the future, this study has the potential to show promising results.

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