HIERARCHICAL INSTANTIATION OF ATTENTION

A Master's Thesis

by
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Ankara
October 2022

To my mother

HIERARCHICAL INSTANTIATION OF ATTENTION

The Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

by

İREM GİRAY

In Partial Fulfillment of the Requirements for the Degree of
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HIERARCHICAL INSTANTIATION OF ATTENTION

By İrem Giray

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Psychology.

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ABSTRACT

HIERARCHICAL INSTANTIATION OF ATTENTION

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Extended task executions involve goal-directed programs that control the execution of component steps. While the presence of such programs is widely accepted, their nature remains unclear. Prior studies saw them as controlling the identity and sequence of individual steps much like how a recipe controls and organizes cooking. However, this can happen only in predictable tasks where the identity and sequence of steps are known beforehand. Programs, on the other hand, are also evident in unpredictable tasks where the identity and sequence of steps are not foreknown. What is the role of these programs in such tasks? It has been suggested that, contrary to existing view, these programs may not be about specifying the identity and sequence of component steps. Perhaps they are the means of instantiating all kinds of goal-related control processes during extended tasks. We tested this thesis in relation to attention. If attention during extended tasks is instantiated via these programs, then attentional focus may be poorer on the initial steps of such tasks, especially if these steps are fast-paced. This is because when a new task starts a new program is needed. If attention can only be instantiated via these programs, then the initial steps cannot be attended unless the new program is in place. However, in fast-paced tasks the initial steps may be at hand before these programs have been assembled. Consequently, these steps may suffer from a lack of attention. We show that attention-dependent inhibitory control is indeed poorer on the initial steps of extended tasks, suggesting that attention may indeed be instantiated via these programs.

Keywords: Sustained Attention, Cognitive Control, Response Inhibition, Hierarchical Control, Goal-directed Programs

ÖZET

DİKKATİN HİYERARŞİK KONTROLÜ

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Birçok adımdan oluşan genişletilmiş görevlerin yürütülmesi amaca yönelik programların aracılığıyla sağlanır. Bu tür programların varlığı yaygın olarak kabul edilse de, doğası belirsizliğini korumaktadır. Önceki çalışmalar, bu programları bir yemek tarifinin yemek pişirme adımlarını kontrol ettiği gibi görevdeki bireysel adımların kimliğini ve sırasını kontrol ve organize eder şekilde konumlandırmıştır. Fakat, bu şekilde bir kontrol yalnızca adımların kimliğinin ve sırasının önceden bilindiği, öngörülebilir görevlerde mümkün olabilir. Öte yandan programlar, kimliğin ve adımların sırasının önceden öngörülemediği görevlerde de gözlemlenmiştir. Bu tür görevlerde bu programların rolü nedir? Mevcut görüşün aksine, bu programların bileşen adımlarının kimliğini ve sırasını belirlemekle ilgili olmayabileceği öne sürülmüştür. Belki de bu programlar genişletilmiş görevler sırasında hedefle ilgili her türlü kontrol sürecini hayata geçirmenin araçlarıdır. Mevcut tezde, bu programların dikkatle ilişkini araştırdık. Genişletilmiş görevler sırasında dikkat bu programlar aracılığıyla başlatılırsa, ve özellikle görev adımları hızlıysa, bu tür görevlerin ilk adımlarında dikkat daha zayıf olabilir. Bunun nedeni, yeni bir görev başladığında yeni bir programın hazırlanmasına ihtiyaç duyulmasıdır. Dikkat ancak bu programlar aracılığıyla başlatılıyorsa, yeni program hazırlanmadan ilk adımlara başlanması mümkün olmaz. Ancak, hızlı tempolu görevlerde bu programlar tam olarak hazır olmadan önce görev adımları başlayabilir. Sonuç olarak, bu adımlar dikkat eksikliğinden dolayı kötü etkilenebilir. Bu tezde, dikkate bağlı ketleyici kontrolün, genişletilmiş görevlerin ilk adımlarında gerçekten daha zayıf olduğunu gösterdik. Bu bulgu, dikkatin gerçekten de bu programlar aracılığıyla başlatılabileceğini gösteriyor.

Anahtar Kelimeler: Sürdürülebilir Dikkat, Bilişsel Kontrol, Tepki Ketleme, Hiyerarşik Kontrol, Amaca Yönelik Programlar

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CHAPTER 1

INTRODUCTION

Imagine making a cup of coffee before starting your work session. When we say 'making coffee', is it composed only of one action or many? You must complete many steps, such as walking into the kitchen, filling the kettle with water, putting coffee into French press, waiting for a while, and finally pouring the coffee into your cup. Even though these actions are entirely different, they constitute the single task of making coffee.

All purposive behavior is executed as tasks composed of many sub-tasks bound to a common goal. The sub-tasks together fulfill the goal. It has recently been suggested that during any task, control processes like attention may be hierarchically instantiated, i.e., brought about by subsuming goal-directed programs (Farooqui & Manly, 2019). At the beginning of tasks, a program related to the entire task is launched. This program will subsume the ensuing task execution and bring the various goal-directed control changes across time. The instantiation of these goal-directed programs are evidenced by the frequent observation of high step 1 RT during all kinds of action sequence execution and that of longer step 1 RT for longer/complex sequences, suggesting that some cognitive entity related to the entire sequence is instantiated at the beginning of execution.

While the presence of these programs is well evidenced, their role remains unclear. One of the aims of this study is to investigate if these programs are the means of instantiating control processes such as attention during extended tasks.

Extended tasks typically involve sustained attention. A goal-directed task focus is sustained across time as the task gets executed. Although the hierarchical execution of extended tasks is well accepted, the relation between sustained attention and hierarchical cognitive control has not been sufficiently explored. Here we study if sustained attention is hierarchically instantiated via the intermediacy of goal-directed programs. Response inhibition tasks, e.g., go/no-go tasks, require sustained attention in order to inhibit the prepotent 'go' response on the occasional and unpredictable no-go trials. In such tasks, the habitual go-response is automatized and not attention-dependent. In contrast, the rare and unpredictable no-go inhibition is highly attention-dependent and suffers massively in the absence of attention (Robertson et al., 1997). Junctures in go/no-go tasks that lack attention will show deficits specifically in no-go inhibition. If programs are the means of instantiating attention, then junctures, where a new program is to be instantiated, will specifically lack attention. This will be especially the case when the trials of go/no-go tasks are fast-paced and limited time is available to respond to a given trial. Part of this limited time will go into assembling the program, leaving less time available for controlled execution of the trial. This should be the case at junctures that participants construe as beginning a new task episode since these will require the instantiation of a new program. Thus, if control processes like attention are instantiated via programs related to the larger task, then accuracy on no-go trials should be poorer at the beginning of extended tasks.

Accounts of response inhibition that do not take such programs into account will make the opposite prediction. Junctures that begin new tasks are marked by slow response times. No-go inhibition depends on the speed of the preponderant go-responses. Slowing down in responding to go-trials makes it easier to stop on the no-go trials. This is captured by popular models of response inhibition that see the go and no-go processes racing for a threshold with the behavior being determined by the winner. Slow go responses make it more likely that no-go process will win the race and lead to successful inhibition. If go response time (RT) on trial 1 of new tasks is slow, then the probability of inhibiting on trial 1 no-go trials should be higher. In other words, existing response inhibition models would predict that accuracy on no-go trials should be higher at the beginning of extended tasks.

Furthermore, sustained attention theories frequently posit that performance in sustained attention tasks decreases with time on task. These would therefore predict better no-go inhibition on early trials and poorer accuracy on no-go trials later in the extended task.

1.1. Sustained Attention

Sustained attention is the ability to focus on a task for an extended period of time. All tasks that are goal-directed and extended in time involve sustained attention. The tasks that measure sustained attention typically ask participants to detect infrequent events and give a response to them. (Christakou et al., 2013; Parasuraman, Warm, & See, 1998; Warm, 1984). Mackworth (1948) was the first to conduct research on sustained attention, which he called ‘vigilance decrement’ at that time. Right after the end of World War II, he was asked to research why British naval radar operators' performance in detecting radar signals from enemy combatants decreased as their watch progressed. New experimental designs were devised that mirror the monotony of the radar-monitoring task (Thomson, Besner, Smilek, 2015). The results of these experiments confirmed that significant decrements occur in performance over time. The conditions that yield vigilance decrements were characterized by a "taxonomy" (Parasuraman & Davies, 1977; Parasuraman, Warm, & Dember, 1987). Based on this taxonomy, researchers devised tasks shorter in duration that still capture vigilance decrement (Nuechterlein et al., 1983). The observation of performance and vigilance decrements, along with self-reports, led to a theory that sustained attention relies on a limited resource that depletes throughout the tasks (Parasuraman et al., 1987).

Robertson et al. (1997) argued that rare targets and the monotonous nature of sustained attention tasks cause lapses in attention that result in performance decrement. The authors stated that lapses in attention could be better measured with a task that requires frequent responses to non-targets and no response to targets. In such a design, when targets occur, active and controlled processing is required to overcome the prepotent habitual response. With the aim of devising such a task, they developed Sustained Attention to Response Task (SART), which is a go/no-go task that requires a response to frequent go trials (91%) and response inhibition to infrequent target no-go trials (11%). Manly, Robertson, Galloway, and Hawkins (1999) argued lapses in attention occur when endogenous modulation fails due to such tasks' monotonous structure. Frequent responding makes responses habitual and induces a mindless state. The role of mindlessness or 'absent-mindedness' in vigilance errors in SART was supported by the finding that participants that had high scores on Cognitive Functions Questionnaire (CFQ; Broadbent, Cooper, Fitzgerald, & Parkes, 1982) did poorly in SART compared to the participants who had low scores (Manly et al., 1999).

Manly et al. (1999) explained the ‘absent-mindedness’ that participants experience during SART through the role of the supervisory attentional system in Norman and Shallice's (1986) framework of control of attention. In this framework, well-learned and routine responses are represented as schemas. The schema with the highest value is executed. The activation level of schemas is controlled by external cues or internal modulation by the supervisory attentional system. When a response needs to be inhibited or a new response should be prepared, the supervisory attentional system exerts a top-down control and modulates the activation level of schemata. When the events are repetitive and separated by long intervals, the supervisory attention system weakens, and the schema that controls the behavior is deprived of internal activation (Norman & Shallice, 1986). When the supervisory attentional system does not boost the activation of the appropriate schema, that schema starts to decay. The decayed schema becomes disadvantaged in the competition with an irrelevant schema that might get activated by external cues. If the supervisory attentional system does not intervene to activate the required schema for successful task execution (e.g., inhibiting the response for the target stimuli in SART), target stimuli are responded to in the same way non-targets are responded. Therefore, successful performance in sustained attention tasks requires the endogenous modulation of attention provided by the supervisory attentional system.

Mind-wandering hypothesis*,* which encapsulates mindlessness or absent-mindedness hypothesis*,* presumes that when the perceptual input from the task at hand fails to maintain the focus of attention, the mind 'wanders' and engages with self-generated, internal, task-unrelated-thought (Smallwood & Schooler, 2006). Mind-wandering during sustained attention tasks can impair performance due to: (1) mind-wandering itself consumes the same attentional resources that are required for the task (Smallwood, 2010); (2) low attentional demands of sustained attention tasks cause understimulation that yields mind-wandering; and (3) during mind-wandering, attention "decouples" from the external task input and becomes directed to internal thoughts (Schooler et al., 2011). Mind-wandering hypothesis is supported by the findings that self-reports of mind-wandering increase with time on task while performance decreases (McVay & Kane, 2012), and performance is worse if the task is too difficult or too easy than the performance when the task is optimally engaging (Molloy & Parasuraman, 1996; Pop, Stearman, Kazi, & Durso, 2012).

Mind-wandering hypothesis is challenged by resource-depletion hypothesis that postulates information-processing of humans is limited at a given time and sustained attention tasks are effortful. The resources for vigilance deplete over time, resulting in a performance decrease (Warm, Dember, & Hancock, 1996). Therefore, two main premises of this account are (1) the amount of resource depletion depends on the demand of task and time on task (Caggiano & Parasuraman, 2004), and (2) as resources deplete, the amount of attention that can be directed toward the task depletes, causing missed targets. This hypothesis is supported by the findings that more challenging tasks indeed cause the largest performance decrements (Helton & Russell, 2013; Helton & Warm, 2008).

Another finding that challenges mind-wandering hypothesis is that participants can form expectancies about target timing by using past experiences and align their attention with the expected target timing. When target stimuli in vigilance tasks are presented in a regular fashion, participants' performance in detecting the target increases (Helton et al., 2005). Although contextual regularities can be learned without conscious awareness (Chun & Jiang, 1998), it has been argued that participants must be mindful of the task to use their knowledge of such regularities for their performance (Baars, 2002; Helton et al., 2005). However, as posited by mind-wandering hypothesis, since the task and mind-wandering depend on the same resource, the participants can still mind-wander without performance impairments if the task is easy enough (Thomson et al., 2015).

Another possibility is that the tasks that require repetitive motor responses to frequent stimuli generate a feed-forward motor routine (Helton, 2009; Doyon, Prenhune, and Ungerleider, 2003). Helton et al. (2005) argue that the supervisory attention system is responsible for canceling inappropriate motor programs (Norman & Shallice, 1986). When a task has a certain temporal pattern, the supervisory attention system can exert top-down control and inhibit the motor program. However, during tasks with unpredictable stimuli frequency, if the participant is distracted, the supervisory system might be unable to interfere and cancel the motor program (Helton, 2009). Therefore, participants during these tasks might fail to inhibit their responses even if they are aware of the stimuli. Helton (2009) emphasizes that this state of distraction or weakened state of the supervisory system is different from the lack of perceptual awareness due to the depletion of resources or mindlessness.

While different theories of sustained attention have different explanations for performance decrement on tasks, they all agree that performance should be good at the beginning and a decrement should occur with time on task. Sustained attention is commonly measured in tasks that require cognitive control (e.g., SART). Therefore, a problem in sustained attention has detrimental effects on cognitive control.

1.2. Cognitive Control

Cognitive control is the ability to pursue goal-directed and intelligent behavior while withstanding automatic and compelling behaviors. It has been described as composed of many cognitive processes, such as working memory, task switching, response selection, and inhibitory control (Sabb et al., 2008). Despite the term cognitive control has been used widely in cognitive psychology and cognitive neuroscience literature, the mechanism underlying cognitive control and whether its components are distinct are unclear (Mackie, Van Dam, & Fan, 2013). The dominant view in the literature is that the components of cognitive control have no interaction (Lenartowicz, Kalar, Congdon & Poldrack, 2010). Nevertheless, some views suggest cognitive control components are separable but also share some degree of commonality (Miyake et al., 2000) or that cognitive control emerges from the interactions of its components (Badre, 2011).

This lack of consensus about the relation among cognitive control components is reflected in functional neuroanatomy. Although cognitive control has been associated with the frontal cortex, especially the prefrontal cortex (PFC; Badre and Desrochers, 2019; Miller & Cohen, 2001), there are two main views regarding the neuroanatomy of cognitive control: componential vs. emergent. The componential view attempts to isolate a control component (e.g., response inhibition) and identify the neural structure that is only responsible for that function (Aron, 2007) or dissociate several components and identify their functional anatomy (Lenartowicz et al., 2010). The emergent view posits that cognitive control arises from the integration of neural resources and distinct networks (Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008).

1.2.1. Inhibitory Control

Inhibitory control, a component of cognitive control, is the ability to control cognition and behavior to override internal predispositions and external distractors to achieve a goal (Diamond, 2013). The term ‘inhibitory control’ has been applied to a broad range of cognitive processes, such as controlling sensory, visual, or auditory distractors, memories, emotions, and countermanding manual, vocal, or ocular responses. The fact that this term has been used so widely has been criticized as limiting its utility to be used as an explanatory construct (Aron, 2007; Friedman & Miyake, 2004; Tiego, Testa, Bellgrove, Pantelis & Whittle, 2018).

Two key cognitive processes of inhibitory control are response inhibition and attentional inhibition. Response inhibition refers to the process of countermanding a prepotent motor response. It is usually assessed using go/no-go, stop-signal, and antisaccade tasks. Attentional inhibition is the ability to resist interference from external stimuli and is assessed by visual matching tasks in which participants compare stimuli while ignoring distracters. Response inhibition and attentional inhibition can also be commonly measured by Stimulus-Response Compatibility (SRC) tasks such as Stroop, Flanker, and Simon tasks (Eriksen & Eriksen, 1974; Kornblum, Hasbroucq, & Osman., 1990; Simon, 1969; Stroop, 1935).

Some studies have attempted to clarify the relation between response inhibition and attentional inhibition. Friedman and Miyake (2004) used structural equation modeling (SEM) to examine the relation between 'Prepotent Response Inhibition' and

'Resistance to Distractor Interference' and found that they were moderately associated. They concluded that this association reflected a common inhibition ability that relies on Working Memory Capacity (WMC) and goal maintenance. The authors stated that this finding is in line with the theoretical perspective that both kinds of inhibition require maintaining the task goal in spite of a prepotent responses or external distractions (Friedman & Miyake, 2004; Kane, Bleckley, Conway & Engle, 2001). However, according to Tiego et al. (2018), since Friedman and Miyake (2004) did not include measures of WMC in their statistical analysis, the commonality of response inhibition and attentional inhibition could not be adequately tested.

Tiego et al. (2018) also argued that previous studies that aimed to distinguish response inhibition and attentional inhibition suffered from a task impurity problem whereby multiple cognitive processes are engaged during the tasks (Friedman & Miyake, 2004). The Dimensional Overlap taxonomy (Kornblum et al., 1990) specifies two types of attentional conflict during Stimulus-Response Compatibility (SRC) tasks which are Stimulus-Stimulus (SS) conflict and Stimulus-Response (SR) conflict. While SS conflict reflects attentional inhibition, SR conflict reflects response inhibition.

Tiego et al. (2018) argued that since previous studies used tasks that combined SS conflict and SR conflict, the commonality of response inhibition and attentional inhibition could have been conflated and tested the hierarchical model of inhibitory control in which response inhibition and attentional inhibition are regressed onto

WMC using structural equation modeling with a sample of 136 11–12-year-old children. In this model, WMC was represented as a higher-order factor that supports response inhibition and attentional inhibition as lower-order factors. The lower-order factors are independent except for their reliance on WMC. The results showed that individual differences in WMC could explain variance in response inhibition and attentional inhibition factors. Furthermore, response inhibition and attentional inhibition were found to be independent factors after accounting for their shared independence on WMC.

1.2.1.1. Response Inhibition

Stopping a prepared but no longer useful response is crucial for goal-directed and flexible behavior in an ever-changing environment. Response inhibition is commonly studied in paradigms that create a prepotent motor response. This prepotent motor response is unpredictably asked to be inhibited on infrequent trials. The most widely used response inhibition paradigms are go/no-go task (Donders, 1969) and stop-signal task (Logan & Cowan, 1984). In go/no-go tasks, participants are asked to respond to a go stimulus on most trials and to inhibit their responses when they see the occasional no-go stimuli. In stop-signal tasks, participants see a 'go-stimulus' (e.g., an arrow symbol) on most trials requiring them to respond (e.g., press left key for left arrow symbol and right key for right arrow symbol). Occasionally, this go-stimulus is followed by a stop stimulus (e.g., a tone) that signals participants to withhold their response.

Both tasks have been used to study response inhibition problems in children and adults with attention-deficit/hyperactivity disorder, patients with schizophrenia, and Parkinson's disease, as well as to investigate the effects of aging and development, and individual differences (Badcock et al., 2002; Bekker et al., 2005; Hershey et al., 2004; Logan, Schachar, & Tannock, 1997; Nielson et al., 2002). In literature, it is common to generalize the findings of stop-signal tasks and go/no-go tasks to each other because inhibition on these tasks is presumed to be achieved similarly (Aron, Robbins, & Poldrack, 2004; Nigg, 2000). However, some accounts claim stop-signal and go/no-go tasks require different kinds of inhibition because while go/no-go tasks require withholding a prepotent response, stop-signal tasks require canceling an initiated response (Eagle, Bari, & Robbins, 2008; Schachar et al., 2007).

Logan and Cowan's (1984) act of control model suggests that control emerges from the interaction between executive and subordinate systems. Executive system forms action goals and issues commands to fulfill the goal. The subordinate system interprets and implements the commands. In response inhibition, the executive system inhibits the response by replacing the go goal associated with go stimuli with the stop goal associated with countermanding the response. When no-go or stop stimuli are repeated, a stimulus-stop association is formed, and the retrieval of this association activates the stop goal and suppresses the go response (Logan & Cowan, 1984; Verbruggen & Logan, 2008). If the stimulus is consistently mapped onto stopping, response inhibition can be automatized, reducing the amount of top-down control needed for successful inhibition (Logan, 1988; Shiffrin & Schneider, 1977; Verbruggen & Logan, 2008). Shiffrin and Schneider (1977) defined automatic processing as the activation of a learned sequence of elements in long-term memory that is triggered by appropriate stimuli. Automatic processing does not require attention, is not subject to capacity limitations, and develops through the consistent mapping between a stimulus and a response throughout the task. Automatic processing is not possible when a stimulus is mapped onto different responses (i.e., varied mapping).

Verbruggen and Logan (2008) claimed that automatic response inhibition could develop in go/no-go tasks but not in stop-signal tasks because of the difference in stimulus-response associations. Consistent mapping is possible in go/no-go tasks because a category of stimuli is always associated with going or stopping. However, stop-signal task leads to varied mapping; a stimulus is sometimes associated with going and sometimes stopping depending on the presence of a stop signal on a particular trial. This means that when the stop goal is activated in go/no-go tasks, the go process could be inhibited without additional control processing, whereas stop-signal task depends on controlled inhibition.

1.2.2. Models of Response Inhibition

Response inhibition is commonly described as a race between go response and stop response. The response that reaches the threshold first wins the race. Horse-Race Model describes this race with relative finishing times. Drift-Diffusion Model describes go and stop processes as two different response boundaries that win the race when information accumulation reaches whichever of them. The assumptions of these models are helpful in terms of how RTs, error rates, and error RTs should relate to each other.

1.2.2.1. Drift Diffusion Model

Drift Diffusion Model is a stochastic model of decision-making on fast two-choice decision tasks that uses RT distributions and accuracy rates to provide insight into latent psychological processes such as speed-accuracy trade-offs, stimulus processing speed, and biases towards a choice (Ratcliff, 1978; Ratcliff & McKoon 2008; Ratcliff & Rouder, 1998). The model has also been applied to response inhibition tasks such as go/no-go tasks since deciding to respond or withhold is crucial for these tasks (Gomez, Ratcliff & Perea, 2007; Ratcliff, Huang-Pollock, McKoon, 2018). The model describes decision-making as an evidence accumulation process with constant drift and random noise. Decision process starts at a point in between two choice boundaries and ends when the accumulator reaches one of the boundaries. The model has several parameters that can explain differences in task performance: (1) drift rate, (2) starting point, (3) boundary separation, and (4) non-decision time.

Drift rate reflects the speed and efficiency of evidence accumulation and it is assumed to be normally distributed across trials. When drift rate is high, RT decreases while accuracy increases and vice versa (Ratcliff, Smith, McKoon, 2015). Drift rate is affected by noise sources such as stimulus characteristics, task difficulty, arousal, previous task-set preparation, and carry-over effects (Karayanidis et al., 2009; Schmitz & Voss, 2012). For example, high-frequency stimuli are reported to have a higher drift rate than low-frequency stimuli (Wagenmakers, 2009).

The starting point for evidence accumulation can change depending on the bias for a choice, and it is assumed to be uniformly distributed. Biases occur when the frequency of a choice is higher than the other or if a choice is rewarded. Biases cause the starting point to approach the biased choice's response boundary. As a result, RT and accuracy for that choice increase. However, since starting point is now away from the other choice boundary, RT for the other choice increases and accuracy decreases. For example, in go/no-go tasks, 'go' trials are more frequent than 'no-go' trials. Therefore, starting point can move toward the 'go' boundary. When evidence accumulation starts close to the 'go' boundary, go response becomes faster and more accurate.

Boundary separation denotes the distance between two choice boundaries and reflects speed-accuracy trade-offs. When people choose to be more accurate than fast, boundary separation widens. As a result, the time it takes for the accumulator to reach a boundary increases. This increased boundary separation yields increased RT and accuracy. When people choose to be fast over accurate, boundary separation narrows down. In this case, RT and accuracy decrease.

Non-decision time parameter captures processes unrelated to the decision, such as stimulus encoding and motor response (Voss, Rothermund, & Voss, 2004). It has also been argued to include task preparation. Non-decision time parameter is longer in switch trials in task-switching tasks (Karayanidis et al., 2009). Non-decision time is longer when participants are not allowed to prepare than when they are allowed to prepare in task-switching tasks (Schmitz & Voss, 2012, 2014). Therefore, non-decision time parameter is also thought to represent the additional preparatory and reconfiguration processes required in tasks.

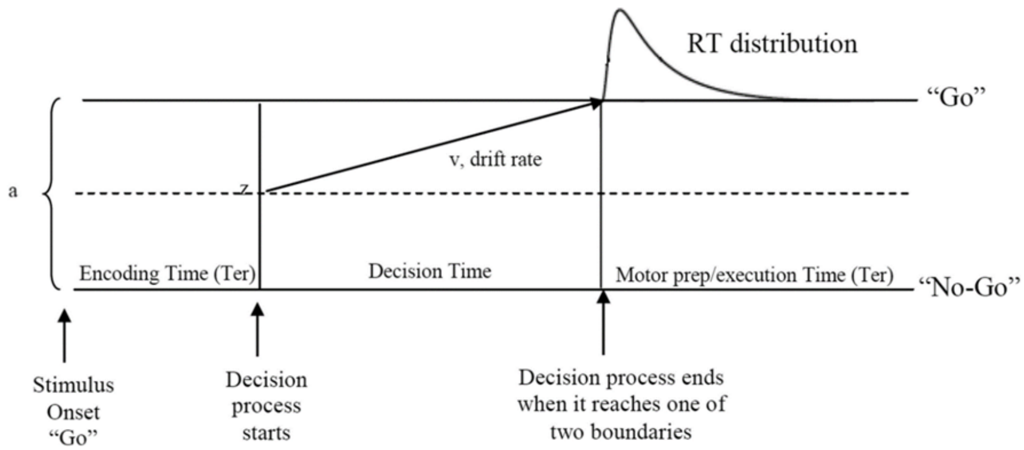

Figure 1.1. Drift-Diffusion Model. Reprinted from "Using the diffusion model to explain cognitive deficits in attention deficit hyperactivity disorder" by C. Huang-Pollock, R. Ratcliff, G. McKoon, Z. Shapiro, A. Weigard and H. Galloway-Long, 2017, *Journal of abnormal child psychology*, 45(1), p. 59. Creative Commons.Depiction of how reaction times are modelled with Drift-Diffusion Model in a go/no-go task. The accumulation of information starts at z after the encoding time (Ter; non-decision parameter) and moves towards either of the choice boundaries. The rate at which evidence accumulates is drift rate (v). Corresponding response is initiated when the accumulator reaches one of the boundaries. The

distance between the boundaries is called boundary separation (a) and depicts participants' strategy in terms of speed-accuracy trade-offs.

1.2.2.2. Horse-Race Models

The common finding in stop-signal task is that participants can successfully inhibit their responses when the duration between go stimulus and stop stimulus (stop-signal delay or SSD) is short. When SSD increases, the probability of inhibition decreases because the stop process is too late to inhibit the prepotent response when there is a delay (Vince, 1948).

Horse-race models formalize response inhibition in stop-signal tasks as a race between the go and stop processes. Ollman (1973) was the first to formalize the relation between the go and stop process as a race; however, this model lacked a precise description of stop process difficulty and inhibition latency (stop-signal reaction time or SSRT). Unlike overt responses such as go RT, SSRT cannot be directly measured. The later versions of race models aimed to account for SSRT. Logan (1981) suggested that the performance in stop-signal tasks can be modeled as a "horse race" between go and stop processes. Go process starts with the stimulus presentation, and stop process starts with stop stimulus presentation. The response is inhibited if stop process finishes before go process (go RT > SSRT + SSD). If the opposite happens (go RT < SSRT + SSD), response inhibition is unsuccessful (Verbruggen & Logan, 2008). In go/no-go tasks, go response is triggered by stimulus presentation because of the prepotent response tendency, and stop process is triggered with the identification of the no-go stimulus (Verbruggen & Logan, 2008).

Logan and Cowan (1984) developed Independent Horse-Race Model that described go and stop processes in terms of finishing-time distributions. This model uses signal-respond RT, no-stop-signal RT, and inhibition functions (i.e., probability of responding when there is a stop stimulus) to estimate SSRT. In the most common forms of stop-signal paradigm, SSD is varied so that participants could inhibit their responses on 50% of trials. Assuming the RT distribution of go trials will apply to no-go trials, SSRT is calculated by finding the 50th percentile of RT distributions and subtracting the SSD from that value.

The measure of SSRT has been important for reporting the differences between different clinical and neurological patients and healthy participants, and lifespan development. The ability to record SSRT also had important implications in understanding the neurophysiology of response inhibition because the neural processes that control response inhibition should occur in a shorter time than SSRT. However, the model does not explain the underlying processes that bring about the finishing times and trial-to-trial variability (Schall, Palmeri & Logan, 2017).

Logan, Van Zandt, Verbruggen, and Wagenmakers (2014) added the choice elements to go and stop processes to Independent Race Model. Special Race Model to estimate the distribution of SSRTs. The parameters in Special Race Model map onto underlying mechanisms of response inhibition. Special Race Model uses the same parameters as Drift Diffusion Model and depicts go and no-go processes as two runners that accumulate information and try to reach the boundary first.

1.3. Hierarchical Control

All tasks are organized in sequences that are directed toward the achievement of a goal. These tasks are composed of smaller sequential events such as tasks and sub-tasks(Badre & Desrochers, 2019). For example, there are many steps to making coffee (e.g., boiling water, putting the cups on the counter, adding coffee, pouring the water into the French press, etc.). The over-arching goal of making coffee runs in the background while executing the steps towards making coffee. The task of making coffee, despite containing many steps, is executed as one task. This execution of tasks with many steps as one entity entails hierarchical control.

With hierarchical control, selection, instantiation, and execution of extended tasks are controlled through one cognitive entity. That cognitive entity controls the thought and behavior throughout the over-arching task episode. Although, How these cognitive entities are formed is unclear (Farooqui & Manly, 2019), it is known that what determines an extended task's being understood as a single entity is the doer's perception of it (Vallacher & Wegner, 1989). This implies that depending on the construal of the doer, what constitutes a sub-task to a task entity might become an over-arching single entity itself. For instance, while making coffee can be a sub-task of preparing breakfast, making coffee can also be construed as a single entity with sub-tasks such as boiling water, putting coffee into French press, pouring water into French press, etc. This, in fact, exemplifies the hierarchical nature of the execution of sequential behavior.

The existence of hierarchical cognition was first recognized in predictable situations where the knowledge about the identity and sequence of sub-tasks is held in the form of cognitive representations such as schemas, scripts, frames, and plans (Miller, Galanter, & Pribram, 1960; Minsky, 1974; Norman & Shallice, 1986; Rumelhart & Norman, 1982; Schank & Abelson, 1977). When participants were asked to recall and execute memorized sequences of task items (e.g., ABBA or ABAB in rule-switching tasks where A and B are different rules), three consistent behavioral signatures of hierarchical execution of tasks were observed: (1) trial 1 RT tends to be the longest in the task sequence (Klapp et al., 1973); (2) trial 1 RT is longer for longer or more complex task sequences (Anderson et al., 1996; Schneider & Logan, 2006); (3) when task sequences require more than one task item being executed, switch-cost disappears when the switch happens across sequence boundaries (Lien & Ruthruff, 2004; Schneider & Logan, 2006). The findings of these experiments were interpreted as the additional time it takes to retrieve task sequences and instantiate the control elements regarding the sequence in working memory.

It has recently been suggested that hierarchical execution is not limited to tasks with predictable sequences. Even when task sequences are unpredictable, as long as they are seen as parts of an over-arching task, behavioral signatures of hierarchical execution were observed. Farooqui and Manly (2019) had participants execute a rule-switching task with two equiprobable rules. The margin color of the trial screen signaled the rule for the current trial, and the rule was not predictable prior to the trial. By presenting a number countdown on the screen and having a bigger inter-trial interval after the last trial, participants were biased to construe 3 to 5 trials as one task episode. When participants perceived 3 to 5 trials as one task episode: (1) trial 1 RT was the longest in the task episodes; (2) trial 1 RT was longer for longer task episodes; (3) switch cost was absent on trial 1 when rule change occurred across task episodes. The presence of behavioral signatures of hierarchical execution in unpredictable task sequences shows that the instantiation of task sequences in working memory cannot be the sole reason. Especially the fact that more prolonged or more complex sequences caused longer trial 1 RT shows the cognitive entity that subsumes the task episode contains control elements regarding the whole episode. It is possible that sequences with different number of steps or different complexitiy levels have different representations that cause different trial 1 RT costs. However, trial 1 reaction time remained high even when participants iteratively executed the episodes with the same number of trials in the study. It is unlikely that participants needed to retrieve the number of trials at the beginning of each episode.

Increased trial 1 RT has also been reported in studies in which short inter-trial intervals separated runs of trials, and a longer inter-trial interval separated the task runs (Gopher et al., 2000; Poljac, Koch, & Bekkering, 2009; Wylie & Allport, 2000). The trial right after the long inter-trial interval had longer RT than the subsequent trials in the run. Increased RT at the beginning of the new run was interpreted as 'restart cost'. It has been argued that long inter-trial intervals break the task-set representation (Altmann, 2002; Altmann & Gray, 2002). Task sets must be strengthened at the beginning of a new run by retrieving task-item representations from long-term memory to working memory. The fact that the restart cost mirrors the task sequence implies hierarchical control (Schneider & Logan, 2006). Farooqui and Manly (2019) argued that this cost stemmed from the perceived length and difficulty of the task episode rather than the long inter-trial interval because trial 1 RT was longer for longer and more complex tasks. It is possible that the period between two long inter-stimulus intervals was perceived as one task episode, and a new cognitive entity needed to be assembled at the beginning of task episodes.

Farooqui and Manly (2019) suggested that the phenomenal experience of executing tasks with many steps as one entity rather than executing each step one by one is possible via a program (i.e., a goal-directed program) that contains the elements that prepare the cognition for the task. The components of this program can change depending on the familiarity and predictability of the task episode related to the task goal. If the task is entirely familiar and predictable, the program can contain individual motor acts that should be executed throughout the task. If the task is less predictable, such as executing a memorized task sequence, the program can contain preparation for stimulus-response rules for the steps of the task sequence. If the task is unpredictable, the program can instantiate goal-directed attention and control processes that will support goal completion.

1.3.1. Goal-Directed Programs

Farooqui and Manly (2019) proposed that the cognitive entity that controls the execution during task episodes are goal-directed programs. These programs are assembled at the beginning of the task and instantiate control related to the whole task episode.

The presence of goal-directed programs was first mentioned in a functional resonance imaging (fMRI) study (Farooqui, Mitchell, Thompson, & Duncan, 2012). Participants were shown single letters at a time and asked to detect pre-determined four-letter sequences. The sequence contained two units of letters: a three-letter word and a single-letter (e.g., CATX). By doing so, participants were biased to conceive these four letters as composed of two different units (i.e., a three-letter word and the additional fourth letter at the end). Participants were instructed to detect the first unit and then the other unit. These different units created a hierarchy within the task. In this hierarchy, while the last letter of the word denoted the completion of the word, the single letter at the end denoted the completion of the whole task episode.

Results showed that the fourth letter that completes the episode elicited greater and more widespread activity than the third letter that completes the first unit. The third letter of the word elicited greater activity than the first and the second letters. Granted that all four letters were identical in attention, working memory load, and task rules, these differences could not be responsible for the activation pattern. The authors stated that the activity pattern could be explained by the conceived organization of task episodes causing a change in cognitive entities. As the task proceeded, the program elements related to the completed parts were dismantled and induced differential brain activity. Completing the word elicited less activity because it only dismantled the program elements associated with the episode's lower-level elements. In contrast, the fourth letter dismantled the programs related to the whole episode (Farooqui et al., 2012). If the elements related to the completed steps indeed dismantled, then the cognitive load should be highest at the beginning of the task episode and should decrease gradually until the end of the episode, when the program dismantles completely. Farooqui and Manly (2018) showed that the Default Mode Network, a network of brain areas that are known to deactivate in the presence of cognitive load, is strongly deactivated at the beginning of a task, and this deactivation gradually decreases as the task steps are completed and finally returns to the baseline. Similar results have been reported by other neuroimaging studies in which the end of behavioral or perceptual task episodes elicits additional activity compared to the previous steps of the task episode (Fox, Snyder, Barch, Gusnard, Raichle, 2005; Fujii & Graybiel, 2003; Konishi et al., 2001; Zacks et al., 2001).

1.4. Current Thesis

Extended tasks with several streps require attention to be sustained for an extended period of time. Attention and other control processes are instantiated to achieve a goal. For goals to control the task episode for their fulfillment, a goal-directed entity (goal-directed programs) has to be instantiated at the beginning of task episodes. Therefore, attention can be instantiated via goal-directed programs. Despite ample evidence for the presence of goal-directed programs, the relation between sustained attention and hierarchical control is yet to be explored. In this thesis, we study if sustained attention is hierarchically instantiated via goal-directed programs.

We used three versions of go/no-go tasks composed of 9-trial episodes to investigate whether attention is hierarchically instantiated via goal-directed programs. We measured RTs, error rates, and accuracy divided by RT (A/RT) for each serial trial position in an 9-trial task episode to analyze how task performance changes throughout the serial positions in task episodes.

Response inhibition tasks such as go/no-go require sustained attention to inhibit the habitual responses on infrequent and unpredictable no-go trials. In such tasks, frequent go trials make the task monotonous and go responses habitual. When go responses become habitual, they are no longer dependent on attention. Response inhibition on no-go trials, in contrast, is highly attention-dependent. If sustained attention is hierarchically instantiated via goal-directed programs, the instantiation phase should cause junctures that lack attention. These junctures should cause increased trial 1 RT for go trials due to both the assembly of the program period and processing and responding to the stimuli occurring on trial 1. For no-go trials, trial 1 error rate should increase because there is less time left to process the stimulus and inhibit the response. However, the theories that aim to explain how performance changes throughout sustained attention tasks consistently predict a better performance at the beginning of tasks and a gradual decrease with time on task.

The prediction of RTs and error rates increasing together, especially on the earlier trial positions is not in line with response inhibition models that depict response inhibition as a race between processes or choice boundaries. According to Horse-Race Model, SSRT is more likely to win the race when RT is slow. Therefore, inhibition success increases with increased RT. In such a scenario, high RTs should be accompanied by low error rates and vice versa. For Drift-Diffusion Model, decision parameters should be in line with go responses because go trials are far more frequent than no-go trials. Since there are no rule representations or memorized sequences to retrieve and instantiate related control processes from memory, decision parameters should not predict a performance decrement on the earlier trial positions.

CHAPTER 2

EXPERIMENT 1

In this experiment, we used a go/no-go task with 9-trial episodes that were separated by self-paced gaps to bias participants to construe each nine trials as a task episode. We calculated reaction time, error rate, and accuracy divided by reaction time (A/RT) for nine serial trial positions.

2.1. Method

2.1.1. Participants

40 healthy participants (*M* = 21.20; 24 females) were recruited through e-mail announcements within Bilkent University. The mean age of participants was 21.20 (*SD* = 2.00; 24 females). All had normal or corrected to normal vision. All gave written informed consent and were compensated with 20 TL or course credit.

2.1.2. Procedure

A Go/No-go task that was coded in Pygame 1.9.6 was used. Participants downloaded the experiment via a link and ran the experiment on their computers. The instructions for the experiment were given on Zoom.

In each trial, participants were presented with either a letter or a number on a computer screen. Each stimulus was centered on the screen and remained for 400 milliseconds (ms). A 700 ms fixation screen followed each stimulus. The stimuli color was white, and the background color was black. The font of stimuli was comic sans, and font size was 54. Participants were asked to respond to letters (i.e., go trials) by pressing the lower arrow key on their keyboards to do not respond to numbers (i.e., no-go trials). Participants were instructed to give equal importance to speed and accuracy. The numbers were between 1 and 9. The letters were from the English alphabet. The ratio of letters and numbers were 80% and 20%, respectively. There were 150 episodes that were composed of 9 trials. Each trial position in the episodes had an equal possibility of containing a no-go stimulus. The episodes were separated by self-paced gaps. The instruction to press lower arrow key for letters stayed on the screen during each gap. Participants pressed space key to start the new episode.

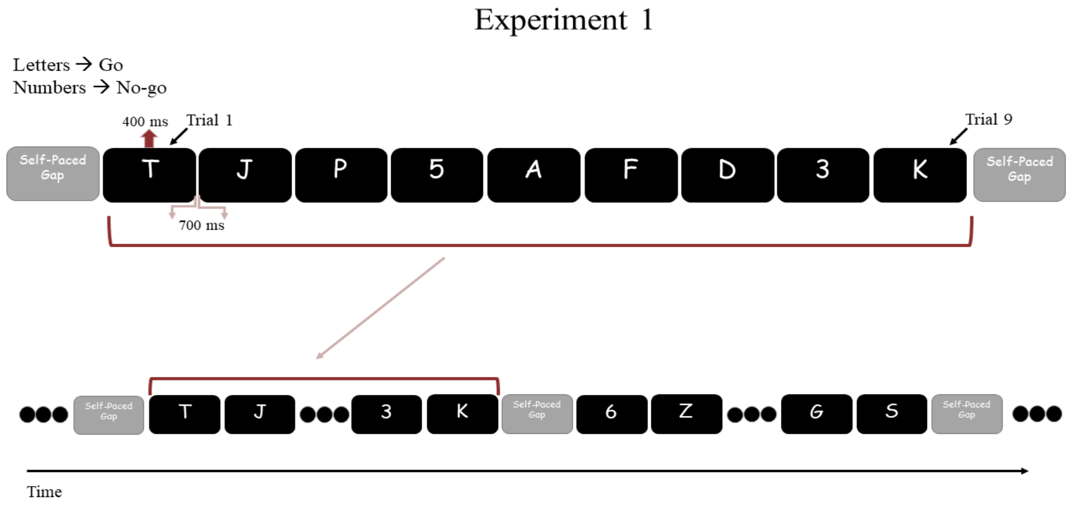

Figure 2.1. Experimental paradigm in Experiment 1. A go/no-go task was used. Participants were asked to press down arrow key for letters and withhold their responses for numbers. Each stimulus was shown for 400 ms, and a 700 ms fixation

screen followed it. Participants were allowed to respond until the end of the fixation screen. A task episode was composed of nine trials. A self-paced gap separated the task episodes.

2.2. Results

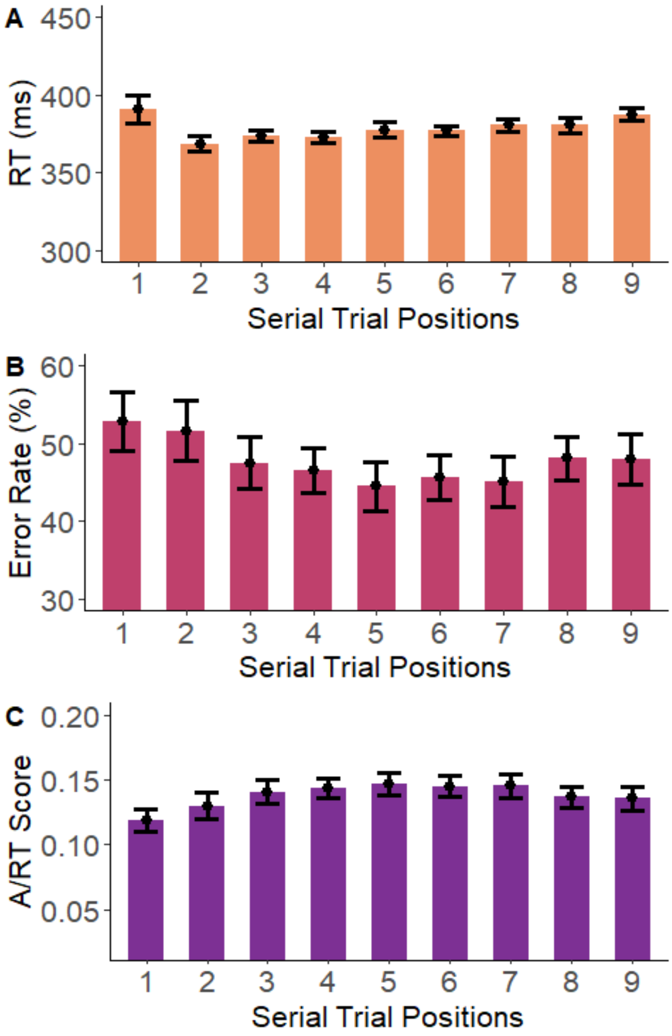

Figure 2.2. Results of Experiment 1: Horizontal axes represent the nine serial trial positions in a task episode. The bar graphs represent (A) reaction time for letter

stimuli, (B) error rates for no-go stimuli, and (C) accuracy divided by reaction time for the trial position.

First five episodes and RTs shorter than 100 ms were excluded from the plots and the statistical analysis. Figure 2.2 summarizes the results for RTs, error rates, and A/RT scores across trial positions in the task episodes. Figure 2.2A displays that RTs are high on trial 1, and there was a drastic decrease on trial 2. From trial 2 onwards, RT values follow a gradually increasing trend. Figure 2.2B shows that the error rates on the first two trials are higher than the subsequent trial positions. Figure 2.2C shows that A/RT scores are lower on trial 1, following an increasing trend on the subsequent trial positions and then decreasing again towards the final trial positions. First five episodes and RTs shorter than 100 ms were excluded from the analysis. Data was analyzed using R (version 4.0.0) using stats (version 4.0.0) package. A repeated measures ANOVA was conducted to determine if there was a statistically significant difference among serial trial positions in an episode for go RT, no-go error rate, and A/RT (accuracy for no-go trials divided by go RT). The results showed that trial position had a statistically significant effect on reaction times ($F(3.51, 136.83) = 8.30$, $p < .001$, $\eta2 = .18$), error rates ($F(8, 312) = 3.12$, $p = .002$, $\eta2 = .07$), and A/RT ($F(8, 312) = 4.44$, $p < .001$, $\eta2 = .10$).

Figure 2.2 shows that Trial 1 RT and error rate were the highest in the episode. A/RT had the lowest value on trial 1. Trail 2 had a close error rate to trial 1(52.87 and 51.67, respectively). The effect of serial trial position was significant for error rate ($F(7, 273) = 2.05$, $p = .05$, $\eta2 = .014$) but for A/RT score ($F(7, 273) = 1.92$, $p = .07$, $\eta2 = .015$).

Table 1. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on Reaction Time for Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	8,312	8.30	< .001	.18

Table 2. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on Error Rate for No-Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	8,312	3.12	.002	.07

Table 3. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on A/RT Score

Effects	*dfs*	*F*	*p*	*η2*
A/RT	8,312	4.44	< .001	.10

2.3. Discussion

We showed that when a task episode started, trial 1 RT and error rate were the highest, while A/RT was the lowest in the episode. The poorer performance on trial 1 than the subsequent trial positions imply the presence of additional processing occurring at the beginning of task episodes unrelated to the internal characteristics of stimuli or the task rule.

Additional processing at the beginning of tasks was explained by Farooqui and Manly (2019) as the instantiation of goal-directed programs. These programs contain control elements that subsume the proceeding task episode and are instantiated at the beginning of tasks. The instantiation phase of these programs causes junctures that lack attention. These junctures cause increased RT for go trials because they are added to the time it takes to process. These junctures also cause errors on no-go trials because the default process in go/no-go tasks with high go probabilities is responding (Robertson et al., 1999). Since response inhibition is an additional process and the instantiation of the programs already takes time, scarce time is left to execute response inhibition. This scarcity of time impairs the success of response inhibition. In our study, the effect of goal-directed programs was limited to trial 1 for RT, while error rate remained high on trial 2. This is likely because the programs are not fully instantiated on trial 1, and the effect is carried over to trial 2. Since go response is habitual, RT is more immune to deficits in attention. However, since response inhibition depends on attention, no-go trial performance could not reach the optimal level until the program was fully instantiated.

Theories of sustained attention posit that performance should decrease with time on task rather than a poor performance at the beginning. According to their predictions, RTs and error rates at the beginning of tasks should be low and gradually increase throughout the task. Trial 1 RT and error rate in our experiment provides evidence against these theories. Mind-wandering hypothesis argues that the monotonous nature of sustained attention tasks leads to mind-wandering (Manly et al., 1999; Smallwood, 2010; Smallwood & Schooler, 2006). As a result of mind-wandering, attention is decoupled from external input, and no-go stimuli should be responded to the same way go stimuli are responded to (Schooler et al., 2011). Participants should spend some time on the task for the task to become monotonous. It is unlikely that participants mind-wandered on trial 1.

Mind-wandering possibility is even more unlikely when the fact that participants themselves initiated the new episode is considered. According to resource-depletion theory, limited cognitive resources should decrease as the task progresses, and performance should worsen (Caggiano & Parasuraman, 2004; Warm, Dember, & Hancock, 1996). Since gaps separated the episodes in our experiments, these resources should have been replenished during these breaks. Therefore, participants should have been able to start the episodes with better performance than on the subsequent trials. Some accounts argue that monotonous tasks that require repetitive responses lead to a feed-forward motor program that the supervisory attentional system fails to inhibit (Helton, 2009; Doyon, Prenhune, and Ungerleider, 2003). These motor programs should be reinforced with time on task and decay during the gaps. Since trial 1 is right after the gap, inhibiting motor programs should be easier on trial 1 than on the subsequent trials, which was not the case in our study.
Models of response inhibition predict a negative relation between RTs and error rates (Logan & Cowan, 1984). In Horse-Race Model, SSRT is dependent on RT. Successful inhibition occurs when SSRT+SSD is faster than RT. Hence, slow RT increases the possibility of inhibition. Likewise, when inhibition is unsuccessful, RT

should be faster than SSRT+SSD. In our study, high trial 1 RT was accompanied by a high error rate, which Horse-Race Model would not predict.

In Drift Diffusion Model, the frequency of stimulus category can affect drift rate and starting point of evidence accumulation (Wagenmakers, 2009). When a stimulus category is more frequent, the drift rate for that category increases, and the starting point approaches that category's choice boundary. In go/no-go tasks, go stimuli are thought to have a faster drift rate or starting point closer to go choice boundary because go stimuli are more frequent than no-go stimuli (Gomez, Ratcliff & Perea, 2009; Ratcliff, Huang-Pollock, McKoon, 2018). These changes in drift rate and starting point parameters should result in faster RTs for go trials.

Since there is nothing inherently different about trial 1 stimuli that can lead to poorer performance for both go and no-go stimuli, an additional processing should be happening. Drift rate is reported to change depending on task-set preparation and carry-over effects in task-switching paradigms (Karayanidis et al., 2009; Schmitz & Voss, 2011). However, since we used a go/no-go task, participants did not have to prepare for the next task episode or inhibit the carry-over effect from the previous task. Therefore, it is unlikely that drift rate changed specifically for trial 1. Another parameter that can get affected by stimulus frequency is starting point, which should be closer to go response choice boundary. Increased trial 1 RT implies that starting point moved away from go choice boundary. In this case, starting point approaches the implicit no-go boundary, making response inhibition easier. However, trial 1 no-go error rate was high. Therefore, starting point change cannot be the underlying reason. A possibility is that participants decided to slow down and be more accurate at the beginning of task episodes, and trial 1 RT increased because of this speed-accuracy trade-off. Then, choice boundaries should move away from each other. In this case, error rates should decrease as RT increases, which was not the case. Furthermore, a lower A/RT score on trial 1 than other serial trial positions shows that participants indeed performed worse on trial 1, rather than using a speed-accuracy trade-off strategy.

It is possible that this additional processing was reflected in non-decision parameter. This parameter captures the processes unrelated to the decision, such as stimulus encoding and motor response, as well as preparatory and reconfiguration processes (Schmitz & Voss, 2012, 2014). Goal-directed programs include control processes required for the specific task episode, which is an implicit preparatory and reconfiguration process. We argue that the instantiation of these programs causes junctures that lack attention that delay stimulus processing. Therefore, goal-directed programs can display themselves as increased non-decision times in Drift-Diffusion Models.

In summary, we argue that goal-directed programs can explain increased trial 1 RT and error rate in the current experiment. A new goal-directed program had to be instantiated when a new episode started after the gap. The time it takes to instantiate the new goal-directed program causes junctures that lack attention and delay stimulus processing. These delays are added to the RT of trial 1 for go trials. Error rates for no-go trials were affected by this additional processing time because of the fast-paced structure of the task. Since responding to the stimuli is the default course of action in the task, with less time to process no-go stimuli, participants could not have enough time to inhibit their responses.

CHAPTER 3

EXPERIMENT 2

In the current experiment, we modified Experiment 1 to separate task episodes with response switches. Participants construed nine trials as one task episode even when there was no off-task period between task episodes. If we can observe the same results as Experiment 1 in the current experiment, it would show us the increased RT and error rate, and decreased A/RT stem from how participants construe the task episodes rather than the time spent off-task.

Another modification in the current experiment is that we did not present the participants with a no-go stimulus on trial 1. Since not giving a response to no-go stimuli increases accuracy, we aimed to avoid inflated accuracy on trial 1 due to participants being too slow to respond. Given that error rate on trial 2 was still high in Experiment 1, we expected to be still able to observe an increased error rate on trial 2. If sustained attention is hierarchically instantiated via goal-directed programs, we should be able to observe an increased trial 1 RT and trial 2 error rate in the current experiment.

3.1. Method

3.1.1. Participants

40 healthy participants were recruited through e-mail announcements within Bilkent University. The mean age of participants was 22.86 (*SD* = 1.62; 22 females). All had normal or corrected to normal vision. All gave written informed consent and were compensated with 20 TL or course credit.

3.1.2. Procedure

A go/no-go task was used. Participants were asked to press down arrow key for letters and withhold their responses for numbers. Each stimulus was shown for 400 ms, and a 700 ms fixation screen followed it. Participants were allowed to respond until the end of the fixation screen. A task episode was composed of nine trials. A self-paced gap separated the task episodes.

The task we used in the current experiment was the same as Experiment 1 except that only go stimuli were shown on trial 1. The other eight trials had an equal probability of containing no-go stimuli. A response switch separated the task episodes composed of nine trials. After every nine trials, a screen that prompts to press the space key was shown for 700 ms, and a 1500 ms fixation screen followed it. Every 5 task episodes (response switch and nine trials) were grouped into blocks. There were 25 blocks in total. The participants could take a break after each block.

Experiment 2

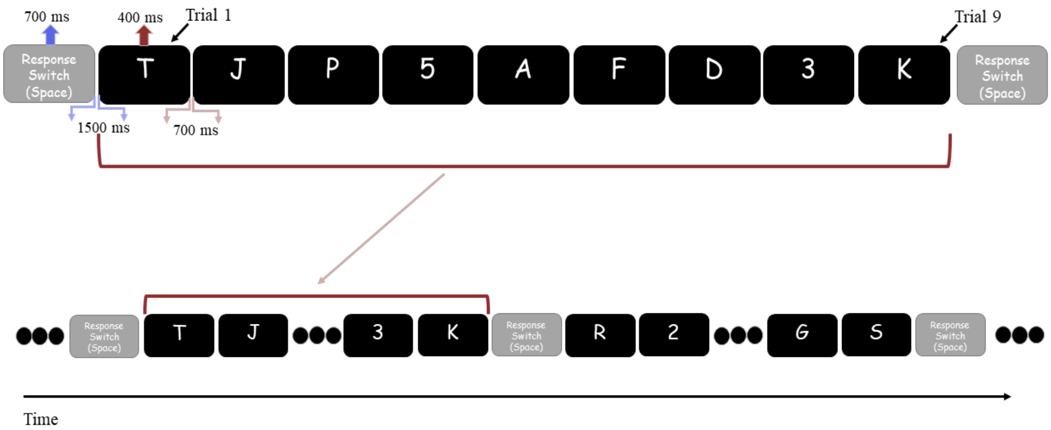

Figure 3.1. Experimental paradigm in Experiment 2. The task was the same as Experiment 1, but the task episodes were separated by response switches that prompted the participants to press the space key on their keyboards.

3.2. Results

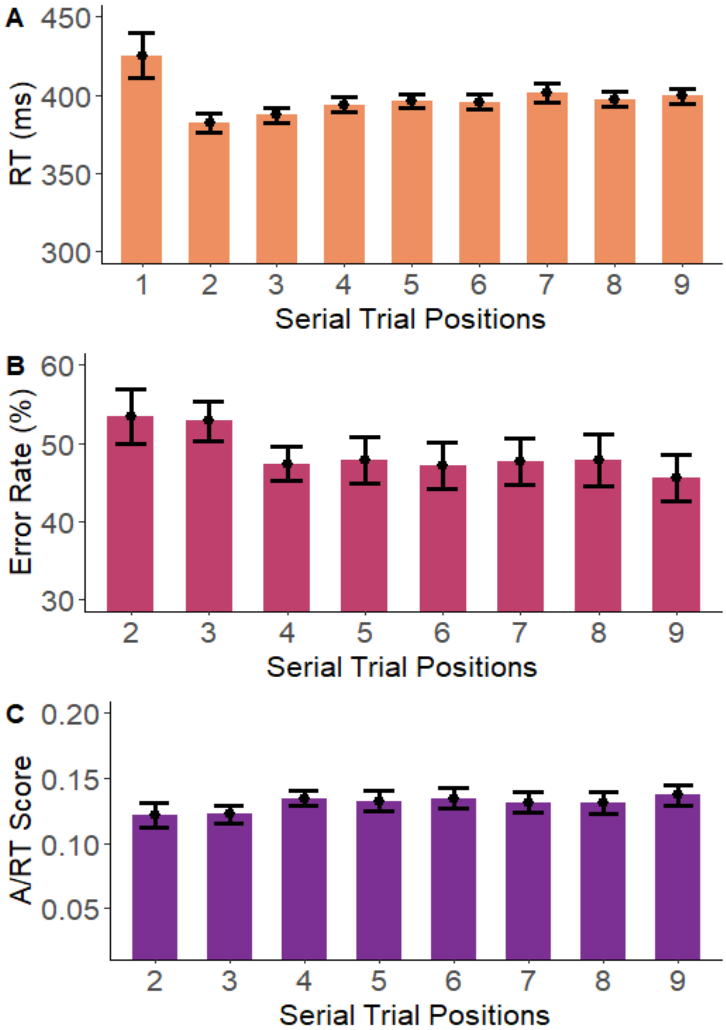

Figure 3.2. Results of Experiment 2: Horizontal axes represent the nine serial trial positions in a task episode. The bar graphs represent (A) reaction time for letter stimuli, (B) error rates for no-go stimuli, and (C) accuracy divided by reaction time for the trial position.

The first five episodes, responses shorter than 100 ms, and the first two trials that follow a break were excluded from the plots and statistical analysis. We also excluded the trial 1 position for error rate and A/RT score since no-go stimuli were not present on trial 1. Figure 3.2 summarizes the results for RTs, error rates, and A/RT scores across trial positions in the task episodes. Figure 3.2A displays that RTs are high on trial 1, and there is a drastic decrease on trial 2. From trial 2 onwards, RT values follow a gradually increasing trend. Figure 3.2B shows that the error rates on the first two trials are higher than the subsequent trial positions. Figure 3.2C shows that A/RT scores are lower on trial 2 and trial 3 and follow an increasing trend on the subsequent trial positions.

We analyzed the effect of serial trial position on reaction time, error rate, and A/RT. Data were analysed in R (version 4.0.0) using rstatix package (version 0.7.0). Serial trial position had a significant effect on RT ($F(2.77, 102.49) = 11.59$, $p < .001$, $\eta2 = .05$), error rate ($F(7, 273) = 3.88$, $p < .001$, $\eta2 = .02$), and A/RT ($F(7, 273) = 2.19$, $p =. 036$, $\eta2 = .02$). Mean response switch RT was 611.60 and error rate was 17.48.

Table 4. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on Reaction Time for Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	2.77,102.49	11.59	< .001	.05

Table 5. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on Error Rate for No-Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	7,273	3.88	< .001	.02

Table 6. One-Way Repeated Measures ANOVA for the Effect of Serial Trial Position on A/RT Score

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	7,273	2.19	= .036	.02

3.3. Discussion

We obtained similar results to Experiment 1 in the current experiment. Participants performed worse on earlier trials than on subsequent trial positions. Trial 1 RT was the highest in the task episodes. We did not measure from trial 1 but trial 2 and trial 3 had higher error rates and lower A/RT scores than the subsequent serial trial positions. The fact that we obtained these results without an off-task period implies that these results stem from how the participants construe the task episodes.

In the current experiment, each block was composed of five task episodes. Participants could take a break only in between the blocks. This new experiment structure that requires continuous responses and focus on the task for a longer time allowed us to test how theories of sustained attention predict task performance better than Experiment 1. Theories of sustained attention, such as resource-depletion hypothesis, mind-wandering hypothesis, or feed-forward motor programs, predict a good performance at the beginning of task episodes and a gradual decrease in performance with time on task regardless of the construed episode structure. The results of the current experiment challenge this prediction. Despite the task being continuous throughout the task blocks, since participants were biased to construe the trials between response switches as a task episode, the behavioral marks of goal-directed programs were present whenever a new task episode started.

We argue that trial 1 RT and trial 2 and trial 3 error rates increased because of goal-directed programs. The instantiation phase of these programs delayed the responses for go trials and caused increased RT. This delay in processing was also detrimental for no-go trials because the scarcity of available time to process the stimuli and inhibit the dominant response was more difficult than the subsequent trials.

CHAPTER 4

EXPERIMENT 3

In Experiment 1 and Experiment 2 we showed that trial 1 RT and error rates on the earlier trials of task episodes increase due to the instantiation of goal-directed programs when participants construe nine trials as one task episode.

In those experiments, task episode structure was foreknown and consistent. However, we mostly experience task episodes in which we know what our task is but do not know how long a task episode will last due to possible interruptions during the task. While reading these lines, we might get a notification on our phones that captures our attention and causes us to pause reading. When resuming reading the text after the interruption, does a new goal-directed program have to be instantiated?

To examine the effect of unpredictable task episodes on the instantiation of goal-directed programs, we devised an experiment in which one block had the same task structure as Experiment 1 (i.e., regular blocks), and the other block had an unpredictable number of trials in task episodes which were separated by gaps with durations that were unbeknownst to participants (i.e., irregular blocks).

In Experiment 2, no-go stimuli never came on trial 1 position following a response switch. In the current experiment, no-go stimuli rarely came on trial 1 after gaps. If goal-related programs are assembled whenever a new task episode starts, whether the task episode structure is known or not, we should be able to observe increased trial 1 RT and increased error rates and decreased A/RT scores on the earlier trials of task episodes.

4.1. Method

4.1.1. Participants

59 healthy participants were recruited through e-mail announcements within Bilkent University and social media. The mean age of participants was 23.77 (*SD* = 4.82; 33 females). All had normal or corrected to normal vision. All gave written informed consent and were compensated with 20 TL or course credit.

4.1.2. Procedure

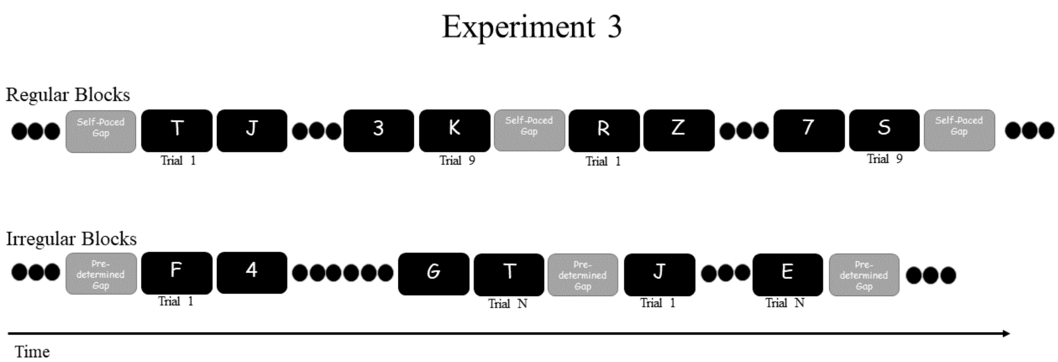

Figure 4.1. Experimental paradigm in Experiment 3. The task was the same as Experiment 1 and Experiment 2. Regular blocks had the same number of trials in an

episode and self-paced gap structure as Experiment 1. Irregular blocks had a random number of trials in an episode and pre-determined durations of gaps.

In Experiment 3, there were two types of blocks: regular and irregular. The episodes in 85 regular blocks had the same structure as Experiment 1. In irregular blocks, there were 85 episodes that were composed of an arbitrary number of trials (from 1 to 58) that were separated by a gap with an arbitrary duration. This manipulation provided a comparison between a structured (i.e., regular blocks) and an unstructured (i.e., irregular block) task. No-go stimuli rarely came on trial 1.

4.2. Results

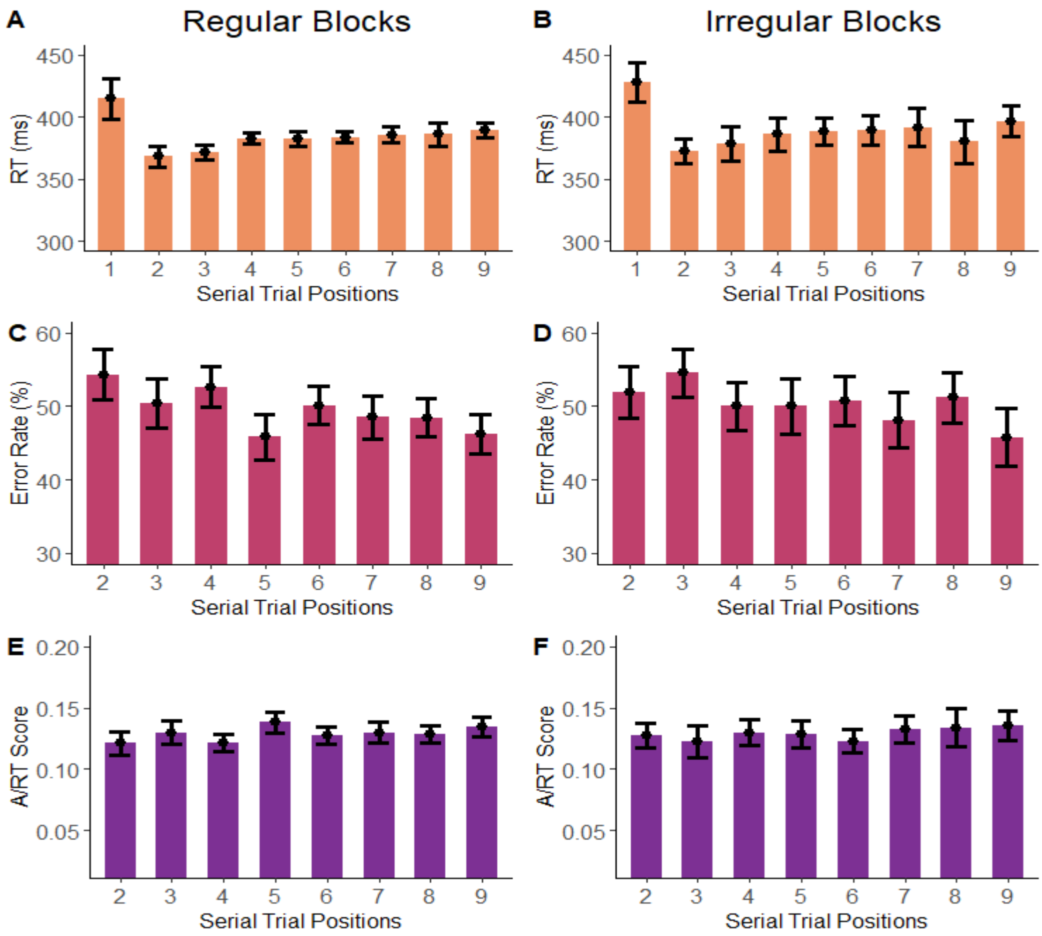

Figure 4.2. Results of Experiment 3: Horizontal axes represent the nine serial trial positions in a task episode. The bar graphs represent (A) reaction time for letter stimuli in regular blocks, (B) reaction time for letter stimuli in irregular blocks, (C) error rates for no-go stimuli in regular blocks, (D) error rates for no-go stimuli in irregular blocks, (E) accuracy divided by reaction time in regular blocks, (F) accuracy divided by reaction time in irregular blocks.

First five episodes and responses shorter than 100 ms were excluded from the plots and statistical analysis. We also excluded the trial 1 position for error rate and A/RT score since no-go stimuli rarely came on trial 1. Figure 4.2 summarizes the results for

RTs, error rates, and A/RT scores across trial positions in the task episodes and block types. Figure 4.2A and Figure 4.2B show that RTs are high on trial 1, and there is a drastic decrease on trial 2 in both block types. From trial 2 onwards, RT values follow a gradually increasing trend. Figure 4.2C and Figure 4.2D show that earlier trials in the task episodes have higher error rates than the subsequent trial positions. Figure 4.2E and Figure 4.2F show that A/RT scores are lower on the earlier trial positions and follow an increasing trend on the subsequent trial positions.

We conducted a two-way repeated measures ANOVA using R (version 4.0.0) program and rstatix (version 0.7.0) package.Trial position had a significant main effect on reaction time ($F(4.05, 234.76) = 10.35$, $p = .009$, partial $\eta2 = .03$), error rate ($F(7,406) = 4.59$, $p < .001$, $\eta2 = .008$) and not on A/RT (**(**$F(5.69, 330.30) = 1.42$, $p = .21$, partial $\eta2 = .00$). Main effect of block type and trial position and block type interaction was not significant for reaction time, error rate, and A/RT.

Table 7. Two-Way Repeated Measures ANOVA for the Effects of Serial Trial Position and Block Type on Reaction Time for Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	4.05,234.76	10.35	= .009	.03
Block Type	1,58	2.17	= .15	.00
Trial Position x Block Type	4.58,265.83	0.58	= .75	.00

Table 8. Two-Way Repeated Measures ANOVA for the Effects of Serial Trial Position and Block Type on Error Rate for No-Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	7,406	4.59	< .001	.008
Block Type	1,58	0.59	= .44	.00
Trial Position x Block Type	7,406	1.39	= .23	.003

Table 9. Two-Way Repeated Measures ANOVA for the Effects of Serial Trial Position and Block Type on A/RT Score

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	5.69,330.03	1.42	= .21	.00
Block Type	1,58	0.00	= .94	.00
Trial Position x Block Type	5.52,320.10	0.88	= .50	.00

4.3. Discussion

Results showed that trial 1 RT was highest in task episodes and error rates on the earlier trials were higher than the subsequent trial positions both for regular and irregular episode blocks. This result suggests attention is instantiated via goal-directed programs even in unpredictable tasks in which there was no task sequence nor foreknown episode structure.

Our results oppose the theories of sustained attention because these theories do not predict poorer performance at the beginning of tasks. Furthermore, different episode structures in regular and irregular task blocks can affect performance trends. Resources can replenish in a proper rest, such as in the regular blocks. Hence, participants should have been able to start the task episodes with more resources and better performance in regular blocks. Since mind-wandering is also hypothesized to use the same resources as tasks (Smallwood, 2010), the gaps in regular blocks should decrease the probability of mind-wandering at the beginning. In addition, since the participants themselves ended the gaps and started the episodes in the regular blocks, mind-wandering is unlikely to be the underlying reason for performance decrements at the beginning of episodes. Furthermore, feed-forward motor programs could decay in these gaps, making response inhibition on earlier trials easier. Overall, theories of sustained attention would predict a better performance at task episode beginnings than the later trials. In contrast, the task episode and gaps in the irregular blocks started and ended in an unpredictable fashion. This unpredictability in task structure could make the participants remain vigilant even during the gaps to avoid missing the beginning of the new task episode; therefore, these gaps were also a part of the task for participants. When gaps are a part of the task, resources may not replenish effectively, and mind-wandering can happen anywhere in the block in irregular episodes. In this case, theories of sustained attention would predict a worse performance on task episode beginnings in irregular blocks than regular blocks. However, we have not observed such a difference between task blocks.

In summary, the lack of difference between task blocks shows that goal-directed programs instantiate attention at the beginning of tasks regardless of the predictability of task episodes. The predictability and prior knowledge about the task episodes can be embedded into the program; however, a program needs to be instantiated even if the task structure is unknown.

CHAPTER 5

GENERAL RESULTS

Throughout three experiments, we tested if sustained attention is hierarchically instantiated via goal-directed programs. We used a go/no-go task that was composed of 9-trial episodes. These episodes were either separated by self-paced gaps or response switches. If sustained attention is hierarchically instantiated, we expected to observe increased trial 1 RT for go stimuli and increased error rates for no-go stimuli on the earlier trials of the experiment. The results of the individual experiments were in line with the instantiation of goal-directed programs.

In this chapter, we combined the data from Experiment 1, Experiment 2, and the regular blocks in Experiment 3 to analyze more data and ensure that the effect of goal-directed programs was consistent across experiments. As in the previous experiments, we analyzed no RT, error rate, and A/RT scores. In addition, we analyzed error RT.

5.1. Results

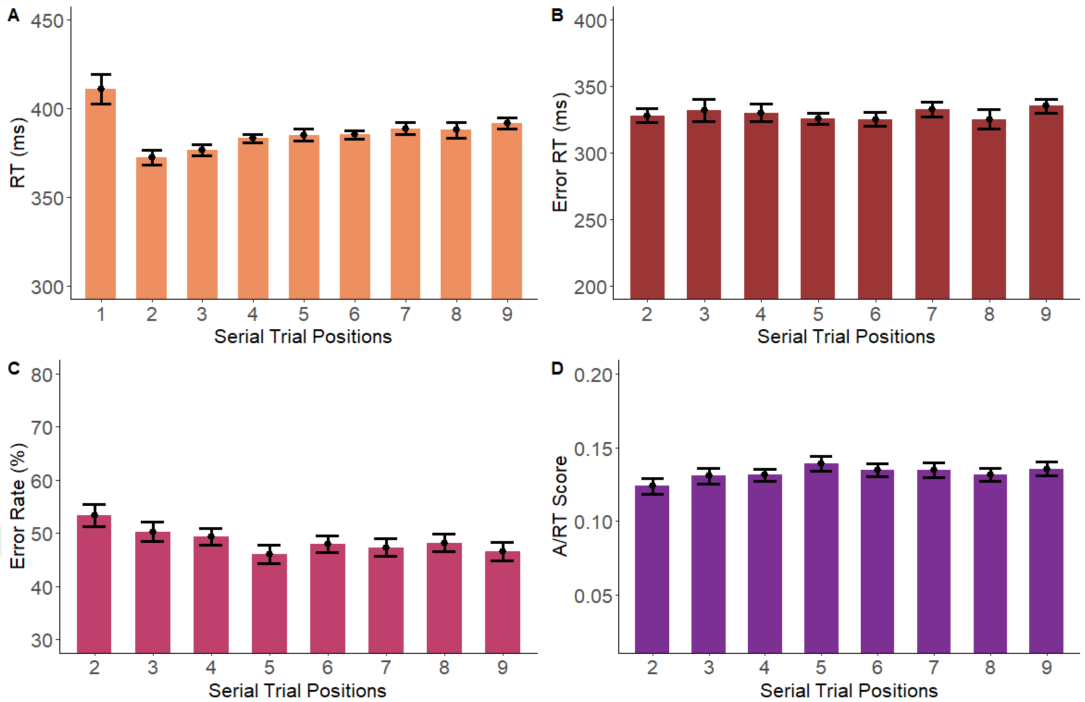

Figure 5.1. Results of the combined data of Experiment 1, Experiment 2, and regular blocks in Experiment 1: Horizontal axes represent the nine serial trial positions in a task episode. The bar graphs represent (A) reaction time for letter stimuli, (B) error reaction time for no-go stimuli, (C) error rates for no-go stimuli, and (D) accuracy divided by reaction time for the trial position.

Figure 5.1. shows RTs, error RTs, error rates, and A/RT scores across serial trial positions. Figure 5.1A shows that RT trend across trial positions starts with a high value on trial 1and, a remarkable decrease at trial 2, and a gradual increase in RT values across the remaining trial positions. Figure 5.1B shows error RTs were stable across trial positions. Figure 5.1C shows error rates follow a trend that starts with a high value on trial 2 and a gradual decrease across trial positions. Figure 5.1D shows

that the A/RT score is lower on the earlier trials in the episode and increases on the subsequent trial positions.

We conducted a mixed measures ANOVA using R (version 4.0.0) program and rstatix (version 0.7.0) package for the effect of serial trial position (within factor) and experiment type (between factor) on RT, error rate, A/RT score, and error rate RT. First five episodes and responses shorter than 100 ms were excluded from the analysis. Trial 1 data for error rate, A/RT score, and error RT were excluded from the analysis since no-go stimuli on trial were reduced or non-existent in the experiments except for Experiment 1.

The results showed that serial trial positions from trial 1 to trial 9 had a statistically significant effect on RT ($F(2.86, 386.24) = 23.29$, $p < .001$, $\eta 2 = .023$). When trial 1 was excluded from RT analysis, the effect of serial trial position was still significant ($F(2.86, 389.24) = 23.29$, $p <.001$, $\eta 2 = .023$). Trial positions from trial 2 to trial 9 had a statistically significant effect on error rate ($F(7, 952) = 6.60$, $p <.001$, $\eta 2 = .010$), A/RT scores ($F(7,952) = 3.35$, $p = .002$, $\eta 2 = .007$), but not on error RT ($F(3.72, 495.16) = 1.43$, $p = .23$, $\eta 2 = .003$). Experiment type and the interaction between trial position and experiment were not significant.

Table 10. Two-Way Mixed Measures ANOVA for the Effects of Serial Trial Position and Experiment Type on Reaction Time for Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	2.86,389.24	23.29	<.001	.023

Experiment Type	2,136	1.08	= .34	.013
Trial Position x Experiment Type	5.72,389.24	1.26	= .27	.003

Table 11. Two-Way Mixed Measures ANOVA for the Effects of Serial Trial Position and Experiment Type on Error Rate for No-Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	7,952	6.60	< .001	.010
Experiment Type	2,136	0.21	= .81	.002
Trial Position x Experiment Type	14,952	1.26	= .23	.004

Table 12. Two-Way Mixed Measures ANOVA for the Effects of Serial Trial Position and Experiment Type on A/RT Score

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	7,952	3.35	= .002	.007
Experiment Type	2,136	0.98	= .38	.010
Trial Position x Experiment Type	14,952	1.18	= .28	.005

Table 13. Two-Way Mixed Measures ANOVA for the Effects of Serial Trial Position and Experiment Type on Error Reaction Time for No-Go Trials

Effects	*dfs*	*F*	*p*	*η2*
Trial Position	3.72,495.16	1.43	= .23	.003
Experiment Type	2,133	0.18	= .84	.002
Trial Position x Experiment Type	7.45,495.16	0.62	= .75	.002

5.2. Discussion

Our combined analysis of Experiment 1, Experiment 2, and Experiment 3 showed that trial 1 RT was the highest, error rates on the earlier trial positions was higher than the subsequent trial positions, A/RT score that reveals the general efficiency of responses was lower on the earlier trials, error RT was not different for different trial positions, and performance on trial positions was not affected by experiment type. These results indicate that when trials are construed as parts of task episodes, the performance on trials is mediated by a common goal-directed program rather than being executed independently of each other.

No-go trial error RTs were stable across trial positions and shorter than go RT. According to Horse-Race Model, when the sum of response inhibition latency (SSRT) and SSD in stop-signal task, the probability of successful inhibition increases (Logan & Cowan, 1984). In go/no-go task, SSD is replaced by the time it takes to recognize no-go stimuli, and SSRT is error RT (Verbruggen & Logan, 2008). Since error RT was stable, the difference in error rates across serial trial positions can be explained by the efficiency in processing the stimuli. In Drift-Diffusion Model, the efficiency of processing the stimuli is accounted by drift rate parameter. Since there is nothing inherently different in the stimuli shown in the earlier trial positions, drift rate should not have been affected by serial trial positions. The effect of trial position has been studied in switch costs in task-switching paradigms, and it has been argued that slower drift rates represent new task-set preparations and carry-over effects (Karayanidis et al., 2009; Schmitz & Voss, 2011). Since there is no need for such preparations or possible carry-over effects in our task, drift rate cannot explain our results. It is more likely that the non-decision time was increased due to the additional processing caused by the assembly of goal-directed programs.

In closing, the combined data from three experiments show that whenever a new task episode starts, a goal-directed program is assembled that governs task rule and attention required for the fulfillment of task goal. These goal-directed programs get assembled at the beginning of the task, and the instantiation phase causes lapses that lack attention. The instantiation phase generates consistent behavioral results: (1) increased trial 1 RT, and (2) decreased response inhibition performance on the earlier trials of task episodes.

CHAPTER 6

GENERAL DISCUSSION

The current thesis examined if sustained attention is hierarchically instantiated via goal-directed programs. We used a go/no-go task composed of 9-trial task episodes that were either separated by a gap (Experiment 1 and Experiment 3) or a response switch (Experiment 2). In addition, we examined if goal-directed programs are assembled in task episodes with unpredictable trial numbers and gap durations (Experiment 3). We showed that whenever independent trials were construed as a task episode via gaps or response switches, (1) trial 1 had the longest RT, (2) error rates were higher on the earlier trial positions of task episodes, (3) A/RT scores that reveal the general efficiency of performance was lower on the earlier trial positions, (4) error RT was stable across trials in the task episodes. These results indicate that executing the earlier trials, especially trial 1, required additional processing that was not related to the intrinsic characteristics of stimuli or task rule but to the construed beginning of the task episode. This episode-related performance decrement suggests a program that governs attention and other control processes, and their related changes across the task episode had to be assembled every time a task episode started.

The presence of these programs had been shown previously in a study that used task-switching tasks, and the results were (1) increased trial 1 RT, (2) longer trial 1 RT for longer or more complex task episodes, (3) disappearance of switch-cost across episode boundaries (Farooqui & Manly, 2019). These programs were called 'goal-directed programs', and their behavioral results were complemented by neuroimaging studies that showed task episode completion elicits additional activity, which provides evidence that goal-directed programs dismantle at episode completions (Farooqui et al., 2012; Fox, Snyder, Barch, Gusnard, & Raichle, 2005; Fujii & Graybiel, 2003; Konishi, Donaldson, & Buckner, 2001; Zacks et al., 2001).

Goal-directed programs are argued to instantiate goal-directed attention and control processes for successful task goal completion. The behavioral cost of the assembly of these programs was increased trial 1 RT, indicating additional processing occurring on trial 1. If participants cannot start the task without the assembly of goal-directed programs, which is evidenced by Farooqui and Manly's (2019) study, junctures that lack attention should occur during the assembly. These junctures can be detrimental not only to RTs but also to error rates in fast-paced tasks such as go/no-go tasks we used in our experiments. Our results confirm this prediction.

The additional time taken by the instantiation of goal-directed programs affects the error rates by decreasing the time available to process and recognize the stimuli. For non-target stimuli such as letters in our experiment, the effect of goal-directed programs was limited to trial 1 because non-target responses are less attention-dependent and more habitual (Robertson et al., 1997). Hence, once the first response was given, it was easier for the participants to continue giving responses. However, since response inhibition depends on attention and could not become habitual, an additional step was required for inhibition. The junctures that lack attention caused by the instantiation of goal-directed programs took away from the time available for response inhibition.

We measured A/RT (accuracy divided by reaction time) for each trial position to examine whether the performance decrement on earlier trial positions was due to speed-accuracy trade-offs or a genuine weakening in attention and control. In speed-accuracy trade-offs, when participants choose to become more accurate than faster, RT increases along with accuracy rate. When participants choose to become faster than more accurate, accuracy rate decreases along with RT. In either case, A/RT stays stable. Therefore, a change in the A/RT score signifies an improvement or deterioration in performance. In our study, A/RT scores at the beginning were consistently lower than the subsequent trial positions, indicating a worsened task performance unrelated to speed-accuracy trade-offs.

The poorer performance at the beginning of task episodes that we have observed in our study is in opposition to theories of sustained attention. Resource-depletion hypothesis posits that sustained attention tasks are effortful and the mental resources available for executing tasks deplete with time on task (Caggiano & Parasuraman, 2004; Warm, Dember, & Hancock, 1996). Hence, this theory predicts good performance at the beginning of the task and a gradual decrease in performance due to the depletion of available resources. Mind-wandering hypothesis suggests the monotonous nature of sustained attention tasks causes cognition to decouple from external inputs and engage in self-generated task-unrelated-thought with time on task (Schooler et al., 2011; Smallwood, 2010; Smallwood & Schooler, 2006). This theory also predicts good performance at the beginning and a gradual performance decrement with time on task. However, since a gap separated the task episodes in Experiment 1 and Experiment 3, the resources should have been replenished during the gaps, and mind-wandering should decrease at the beginning of the task episodes since the participants themselves finish the gap and start the new task episode. Therefore performance should have been good at the beginning of task episodes and decreased gradually with time on task, which was not the case.

Response inhibition models also could not predict poorer performance at the beginning of task episodes. Horse-Race model depicts response inhibition as a race between go process and stop processes (Logan & Cowan, 1984). The successful response inhibition occurs when RT is longer than the sum of SSRT and SSD in stop-signal tasks. SSD is replaced by the time it takes to process and recognize no-go stimuli in go/no-go tasks (Verbruggen & Logan, 2008). In Experiment 1, in which we could measure both RT and error rate on trial 1, both RT and error rate was higher on trial 1 than the subsequent trial positions. The fact that response inhibition was poorer on trial 1 although RT was higher, contradicts the model.

Drift-Diffusion Model's decision parameters could not explain the combination of high RT and high error rate on trial 1. Drift rate and starting point are reported to be affected by the stimulus category in decision-making tasks (Ratcliff & McKoon 2008). The studies that modeled go/no-go tasks using Drift-Diffusion Model reported that the drift rate for go responses is faster than for no-go responses, and the starting point of evidence accumulation is closer to go response choice boundary (Gomez, Ratcliff & Perea, 2009; Ratcliff, Huang-Pollock, McKoon, 2018). The result of these parameter changes is that go responses have fast RTs. However, they have different predictions pertaining to how no-go response error rate is affected. If starting point is moved away from go response choice boundary and approaches the implicit no-go choice boundary on trial 1, then RT should increase while error rate decreases. Therefore, starting point could not explain the general performance decrement on trial 1. If drift rate is faster for go response and slower for no-go responses because go trials are more frequent, go response RT should be low while no-go error rate increases. Our results, especially of Experiment 1, show that trial 1 RT and error rate increase together, which implies a general deterioration and slowing down of stimulus processing. Since there is nothing inherently different in trial 1 stimuli, this result can only be explained by additional processing occurring at the beginning of task episodes. This additional processing has been modelled with drift rate parameter in task-switching paradigms, and decreased drift rate in switch trials has been argued to reflect task preparation and carry-over effects (Karayanidis et al., 2009; Schmitz & Voss, 2011). However, since there is no need for this kind of processing in our task, the additional processing we observe can be explained by goal-directed programs. Since these programs cause junctures that lack attention and delay stimulus processing, it is likely that the assembly of goal-directed programs that instantiate goal-directed attention is governed by non-decision parameter.

In summary, the results of our study suggest that sustained attention is instantiated via goal-directed programs that subsume the whole construed task episode and contain control-related changes, and prepares the cognition throughout the task episode for the fulfillment of task goal. These programs are assembled at the beginning of task episodes and cause lapses that lack attention which delays the task execution. This delay in sustained attention tasks results in a longer trial 1 RT and a higher error rate on the earlier trials.

6.2. Limitations and Future Directions

The task episodes in our experiments were separated either by gaps or response switches. In experiments where the episodes were separated by gaps (Experiment 1 and regular blocks in Experiment 3), participants had to press the space key to finish the gap. Therefore, the gaps also involved a response switch.

In a further study, the effect of goal-directed programs should be differentiated from response switches. This can be possible via two different experimental designs. An experiment involving response switches within episodes in which participants are required to press a key different than the usual response key (e.g., down arrow key in our experiments) for a specific kind of stimuli on different trial positions (e.g., letters written in color red) could be useful. In such an experiment, if the results show that performance on trials that follow the instantiation of goal-directed programs is worse than on the trials that follow within-episode response switches, this would provide evidence that the effect of goal-directed programs is different and more robust than mere response switches. However, in such a design, participants can perceive the episode divided into two as the beginning of the episode and the trials after the response switch.

Another possible experimental design can be biasing the participants to perceive the initiation of a new episode via a colored frame and a longer inter-trial interval, like in Farooqui and Manly’s (2019) study. In such an experiment, the colored frame should come at the last trial position, and the previous trials in the episode should be frameless so that the effect of goal-directed programs should not be mistaken for the additional processing stemming from the processing of the colored frame. If the performance decrement can be observed on the earlier trials as in our study, this result would indicate the effect of instantiation of goal-directed programs independent from response switches.

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