'Oops! I can't believe I did that!'

Inducing Errors in a Routine Action Sequence

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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ABSTRACT

'What was I thinking ?!?' – No matter age, intelligence or social status, we all experience moments like these. Perhaps it is walking into a room and forgetting what you went there to do or maybe failing to add sugar to your coffee due to an interruption. Regardless, even though many of our daily activities are accomplished through routines that require very little conscious effort, errors of attention or slips of action do occur. This collection of studies was designed with three main questions in mind: 1) can action slips be induced in a laboratory-based task (Slip Induction Task; SIT), 2) how well do currently established theories of action slips explain the errors that are induced within the SIT, and 3) what insight can be gained about preventing such errors?

The first experiment was developed to replicate previous findings regarding the effectiveness of the SIT, as well as to determine the extent to which SIT performance correlates with other measures of attention failure. The study discussed in Chapter 3 expands on those results by investigating the effects of healthy aging on slip induction and finds that while older adults were better able to avoid action slips, they appear to sacrifice speed for accurate performance. The goal of the subsequent study was to determine whether young adult participants would also enjoy increased accuracy if they completed the task at a slower pace. Finally, the study discussed in Chapter 5 looks at whether changing the goal of the SIT would alter participants' ability to inhibit unexpected cue information.

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CHAPTER ONE: General Introduction

Try to imagine yourself sipping a warm cup of coffee on a sunny Saturday morning while you run though the long list of last minute details for your daughter's fourth birthday party that begins early this afternoon. As you reach the point on the list that refers to getting the candles out from the back of the cupboard you hear your eight-month-old baby start crying from his crib. You set down your coffee, congratulate yourself on almost finishing the cup and head to the nursery to start your infant's morning routine. First up, a diaper change, you do a quick calculation in your head of how many diapers you have changed since this little one arrived and determine that double-digit multiplication is not something you want to try out this early in the morning. After a kiss and a hug for the baby, you hear your daughter call out from the kitchen that she's hungry, "…but don't worry, I'm a big girl now, I can reach the cereal and milk all by myself…" Not to worry though, you are like a professional at this diaper change thing so you reassure yourself that you'll make it back to the kitchen before any milk gets spilled on the floor. Then the doorbell rings, the dog starts yelping and your baby's crying becomes intolerable, but no worry, you are at the door, changed baby in tow by the second ring. Its not until the UPS man stares at your baby incredulously that you realize that somehow, in the midst of all the commotion, you managed to squeeze a doll's tutu on your baby boy's bottom instead of a diaper. Very soon after, the gravity of the situation becomes apparent as you realize that the tutu offers no protection from your baby boy's need to relieve himself – all over the floor, your arm, and the brand-new outfit that you bought especially for the birthday party!

Even though not everyone has experienced a situation quite like what was just described, it does not require very much thought to remember a similarly frustrating personal example of a moment when your actions did not reflect your best intentions. Perhaps you've mistakenly put shaving gel in your hair on a particularly rushed morning, failed to add sugar to your coffee because you were interrupted by a phone call, or missed a left-hand turn into the grocery store and instead traveled along your regular route home, seemingly forgetting that you needed milk. Regardless of the error, it is quite apparent that errors of this sort, often referred to as slips of action or action slips, impact virtually everyone at some point in time. Importantly, action slips are characterized by errors that occur during routine, well-known tasks. Take for example the diaper changing incident described above: this error was not something that the poor mother could have avoided if only she had consulted the How-To baby book on her coffee table more closely. No, action slips are not the types of errors that novices make. Instead, they occur in highly routine actions, where the person has become quite skilled at the task but for one reason or another, is unable to complete the task accurately.

In fact, research on slips of action, has indicated that they are especially prevalent at points in time when conscious attention to the task at hand is either absent, disengaged or insufficient. During this lapse of attention, inappropriate, automatically triggered sequences of action are employed (Robertson, Manly, Andrade, Baddeley & Yiend, 1997) and errors result. Early studies of action slips conducted by Reason and colleagues have revealed that these unintended, automatic action sequences are particularly apt to occur when performing highly practiced tasks in familiar environments (Reason, 1977; 1979; 1984; Reason & Mycielska, 1982). Furthermore, Broadbent, Cooper, FitzGerald &

Parkes (1982) have expanded theoretically upon this finding to suggest that these familiar tasks and familiar environments make very few demands on our conscious attention and as such, resources are available to think about or do a number of other things which leaves us vulnerable to distractions, boredom and slips.

Unsurprisingly, William James (1890) alluded to this exact theory in his *The Principles of Psychology* when he wrote that "habit diminishes the conscious attention with which our acts are performed." While James did not go further to describe what might be the effect of less conscious attention to routine tasks, it is not a stretch to assume that such a decline in conscious attention could yield errors under certain conditions. So it should have followed that James' early contemporaries would pursue this question but in fact it was not until almost 100 years later that these errors of habitual tasks became the focus of a research program. Even then, James Reason, almost exclusively, became particularly interested in this type of error.

Reason's Diary Studies

To better understand the circumstances under which people make these everyday errors of inattention Reason conducted a diary study in which he asked participants to keep detailed accounts of situations in which the actions that they performed were different from what they had intended, the date and time of the mistake as well as a general account of the circumstances surrounding the slip (1977). A total of 433 incidents were reported by thirty-five participants over a two-week period, an average of less than one per day and while this study provided considerable insight on the subject of action slips, Reason was interested in learning about the circumstances that contribute to errors in more detail.

As a result, Reason's second diary study required his sixty-three participants to take even more detailed notes about their action slips. Participants were to record, in addition to the date and time of the slip, the nature of their intended action(s), the nature of their erroneous action(s), their mental and physical states at the time of the errors and the environmental conditions when the errors were committed. From these accounts, Reason determined that errors could be characterized as either the result of a poorly established plan, or because of problems that occurred during the execution of a perfectly good action plan (Reason, 1979; 1984; Reason & Mycielska, 1982). The types of errors that result from perfectly good plans, Reason aptly termed 'actions-not-as-planned' and it is these that are more recently referred to as slips of action.

Reason's Error Classifications.

Within the category of 'actions-not-as-planned' the results of Reason's diary studies (1977; 1979; 1984; Reason & Mycielska, 1982) led him to further classify errors into one of four behavioral categories. Firstly, actions that involve the repetition of one or more steps within the sequence, i.e., putting an ingredient into a recipe twice, were quite suitably named repetitions. Intrusion errors were classified as errors in which inappropriate actions are incorporated into a sequence of actions (i.e., mistakenly adding orange juice to one's morning cereal). Thirdly, omission errors were quite common mistakes in which a required action is not completed, like failing to add sugar to a familiar recipe and finally, actions directed towards inappropriate objects (i.e., trying to use a comb to brush one's teeth) were termed wrong object errors. As mentioned earlier, an important feature of Reason's classification of 'actions-not-as-planned' is that the intention for the action is sound but that something happens to create a mismatch between the plan and the actual movements. Thus, Reason notes that within this category of 'actions-not-as-planned' all four of the error types contain actions that are perfectly acceptable under different circumstances. For example, adding cream to a cup of coffee seems like a perfectly acceptable act if one takes cream in their coffee, however, when preparing a cup of coffee for a guest who drinks their coffee black, this action would be considered erroneous.

Reason's categorization of action slips emphasizes that the hallmark feature of errors of this sort is a mismatch between a proper plan/intention for action and the actual movement(s) that are made. As such, under different circumstances, if that particular action had been intended, the actual execution of the action is correct. While Reason did theorize on the possible precursors of action slips, his diary studies revealed that slips were most frequent during the execution of activities that were highly practiced, routine and "largely automatic" (Reason & Mycielska, 1982). This led Reason to conclude that "these mistakes are the price we pay for being able to carry out so many complex activities with only a small investment of conscious attention" (Reason & Mycielska, 1982, pp. 243).

Critical Decision Points.

Importantly, while Reason admitted that at most times conscious attention to a routine task is not entirely necessary, he did suggest that attention to the task goals and what actions had already been completed to achieve those goals, was absolutely required at 'critical decision points' or points in an action sequence where a decision had to be made about how to proceed. In fact, Reason suggested that should any error be made in an action routine, it would be the result of insufficient attention at these junctures

(Reason, 1979). To illustrate this point, consider making a cup of coffee for a friend. After pouring the coffee into a mug, one must consider if he/she asked for cream and after determining that cream should be added, one must consider whether sugar should be put in his/her coffee as well and if so, whether or not sugar was already added at an earlier step of the coffee-making sequence. Reason purported that if these questions were not considered at these critical decision points, repetition, intrusion and/or omission errors were possible (1979; 1984; Reason & Mycielska, 1982).

Attention, Automaticity and Errors

Though often criticized by his peers for his subjective, self-report measures, Reason believed insight into these errors of attention were of interest, not only because they sometimes had quite devastating consequences, but more so because of the information they could suggest about the proper workings of attention and the overall functions of the mind. Since so much debate remains, even today, on exactly what attention is, Reason's approach was that if something can be learned about dysfunctional attention, perhaps somewhat of a consensus can be reached about at least some aspect of proper attention functioning.

Now considered a cognitive psychology Bible of sorts, James's *The Principles of Psychology* (1890), suggests that, "[attention]… is the taking possession of the mind in clear and vivid form, of what seems several simultaneously possible objects or trains of thought. Focalization, or concentration, of consciousness is of its essence; it implies withdrawal from some things in order to deal more effectively with others" (James, 1890, pp. 403-404). Central to this definition of attention is the idea that attention is, necessarily, a limited commodity and as such, must be selectively allocated at any given time to a limited number of tasks.

To allow for this selectivity it becomes important to conserve attention resources whenever possible. This conservation effort includes attempting to suppress irrelevant information when attending to Task A (Tipper & Baylis, 1987) as well as putting off all other goals unless one is so efficient at executing Task B that it requires very minimal conscious attention. Therefore, as James (1890, pp. 113) states, "… if practice did not make perfect, nor habit economize the expense of energy … we would be in a sorry plight…" Unfortunately though, it is this exact act of attempting to spread around attentional resources that can lead to errors in routine tasks.

Just as James (1890) and Reason (1979; 1984; Reason & Mycielska, 1982) have suggested, few today would argue that action slips are the penalty that is paid for the automatization of actions since the likelihood of slips is strongly correlated with one's experience with a task. With respect to cognitive processes, Norman & Shallice (1986) use the term 'automatic' to describe actions or behaviors that can be performed with ease and without interfering with other simultaneous tasks. Typically this is possible because the automatically executed task does not require many attentional resources (Norman and Shallice, 1986). Importantly though, like discussed above, this definition implies that attention is of a limited supply so when the tasks at hand require more attention than is available, impaired performance on one or many of the tasks is likely to result.

Even with this limit to conscious attention, we are still able to multitask with extreme ease and errors within those tasks are relatively infrequent. This ability certainly points to the effectiveness of human information processing but the actual mechanism(s) through which our multitasking abilities are made possible remain up for debate. Norman & Shallice (1986; 2000) and Shallice & Burgess (1993) have developed one such explanation however that seeks to explain how our actions are carried out, either in a largely automatic fashion or through direct, conscious attentional control.

Norman and Shallice's Model of Action.

This model implicates two attentional control systems which, while based on different underlying neural networks, work separately at times and together at other times to accomplish action goals. In order to allow for simultaneous action production, the contention scheduling system (CS) is responsible for controlling well-learned actions. This system operates primarily outside of conscious attention and as such requires very little attention resources and it is only when forced to consider the overall goals of a routine action (like at critical decision points) that conscious attention becomes allocated to the well-learned task (Schwartz, 1995). And while this allocation of resources certainly makes sense from an efficiency point of view, actions controlled by this 'auto-pilot'- like system are also more vulnerable to errors if conscious attention is not switched back to the routine task at those critical decision points.

The supervisory attention system (SAS) is the mechanism that is responsible for monitoring the goals of any routine task that is usually controlled by the CS. Whenever the goal of that well-learned task violates the routine it follows that the SAS is responsible for exerting inhibitory action over the learned, habitual response and to guide actions toward what is necessary for achieving the new goal. It is also this system that is responsible for controlling the attention necessary for the execution of new or potentially dangerous tasks (Norman & Shallice, 1986; 2000; Shallice & Burgess, 1993).

These researchers postulate that slips of action, like those characterized by Reason (1977, 1979, 1984; Reason & Mycielska, 1982) occur for a number of reasons. Intrusion errors, inappropriate actions being incorporated into an action sequence, for example, could be due to environmental triggers that are not inhibited by supervisory attentional control. Regardless, however, all of these types of errors are suggested to result from a failure in switching from the 'auto-pilot' contention scheduling system to the more consciously controlled supervisory attention system at those critical decision points.

Achieving Automatization.

Critical to Norman and Shallice's model of action is the idea that with increased experience with a task, the task becomes routine, and the execution of the task becomes highly automatic. What remains unclear however is how much experience with any given task is required to achieve that level of automatization. While some research on implicit sequence learning has suggested that several hundred or even several thousand repetitions of an action sequence are required (Nissen & Bullemer, 1987; Willingham, Nissen & Bullemer, 1989), Giovannetti, Schwartz & Buxbaum (2007) found routinization after just 10 trials of a coffee-making task. Despite this disparity in the amount of practice required to achieve some level of automatization, it is clear that once the CS becomes responsible for the execution of a task and conscious attention becomes allocated elsewhere, error proneness during those routine tasks becomes significantly elevated.

Theoretical Explanations for 'Actions-not-as-Planned'

While Reason and Mycielska (1982), Robertson et al (1997), Manly, Robertson, Galloway and Hawkins (1999) and Norman and Shallice (1986) have proposed that everyday errors of routine tasks occur because of insufficient conscious attention and a failure to actually check on task goals, other research has pointed to additional precursors to action slips. Wallace, Vodanovich and Restino (2003) have identified a correlation between error proneness as measured by the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald & Parkes, 1982) and boredom and daytime sleepiness in young undergraduate students and even more so in young military personnel. In addition, dual-task conditions also appear to predict action slip likelihood insofar as they divide attentional resources as evidenced by research from Botvinick and Bylsma (2005), Humphreys, Forde and Francis (2000), Giovanetti, Schwartz and Buxbaum (2007) and Giovannetti and colleagues (2010).

Similarly, while not exactly a dual-task experiment, Betch, Haberstroh, Molter and Glockner (2004) had their participants make routinized decisions with or without time pressure. They found that despite intentions to change their habitual decision, making choices under time pressure created a mismatch between intentions and actual behavior, or in other words, a slip of action. Furthermore, failures to behave according to intention were not circumvented, even when those intentions were deliberated upon and rehearsed. Instead, under time pressure, participants often maintain their habitual response.

Others have theorized that errors in routine actions are the result of degraded *online* representations of the overall task (Botvinick & Bylsma, 2005). Motivated to investigate slips of action in everyday tasks within a laboratory environment, Botvinick and Bylsma (2005) asked participants to make fifty cups of coffee while being occasionally interrupted either in the middle or at the end of one of the coffee-making actions (i.e. adding sugar). Their results indicated accurate coffee-making was equally affected by disruptions that occurred in the middle or at the end (nearer to a critical decision point). Botvinick and Bylsma (2005) have explained these results by theorizing that contextual information about a task is represented online and as such, can be disrupted at any point in the action sequence – not just at the end when a decision must be made about how to proceed.

Still, others have shown that slips of action are especially prevalent in the presence of external, environmental distracters, especially for participants who are cognitively impaired in some way (Buxbaum, Schwartz & Montgomery, 1998; Giovannetti et al, 2010). All of these potential explanations however, boredom, sleepiness, dual-task demands, external distracters, time-pressure and degraded task context are perhaps not exactly reasons for why slips occur but instead, why the SAS is not deployed to draw attention to the central routine task when necessary.

Distractions and Suppression.

It is particularly likely that the SAS will fail to be deployed to the routine task when necessary if it is otherwise engaged in attending to internal or external distractions. Whereas few researchers have attempted to study action errors under conditions of internal preoccupation, a number of studies have been conducted to examine the impact of environmental distracters on action production. Much of the literature in this area is focused on patient populations (primarily victims of traumatic brain injury, patients with apraxia and Alzheimer's as well as patients with executive dysfunction) and there is overwhelming agreement that within these impaired populations, errors on everyday tasks are significantly correlated with an increased presence of distracters (Buxbaum, Schwartz & Montgomery, 1998; Giovannetti et al, 2010; Robertson et al, 1997; Schwartz, 1995).

In addition, research by Hasher, Stoltfus, Zacks and Rypma (1991), has also revealed a decreased ability to deal with external distracters within a healthy aging sample of participants. This experiment focused, not on slips of action necessarily, but on the ability to inhibit/suppress distracters using a negative priming paradigm similar to that which has been used by Tipper (1985; Tipper & Cranston, 1985; Tipper & Baylis, 1987; Tipper & Driver, 1988) with healthy young adults. In Tipper's studies, young adults were shown to successfully inhibit distracters with relative ease. In fact, the young participants exhibit a behavior referred to as negative priming where whenever a task entails finding an item in the presence of distracters, participants' response to an item which was recently a distracter, is slowed. In other words, if on trial one a participant is searching for an 'x' in a visual array where 'o' is the distracter item, finding an 'o' in an array of 't's on trial two will be particularly slowed, much more than if the participant was searching for any other letter.

While Tipper has found evidence of a general likelihood to suppress distracting information in young adults (Tipper, 1985; Tipper & Cranston, 1985; Tipper & Driver, 1988), Hasher, Stoltzfus, Zacks and Rypma (1991) have found that older adults do not show this negative priming effect. Instead, the authors suggest that with increased age, one's ability to ignore/inhibit/suppress distracting information is impaired and they suggest that it is this inability to suppress that leads to many of the cognitive failures that are seen in an aging population. Indeed, Layton (1975) has suggested that older adults are more affected by both external distracters in the environment and internally generated distracters (e.g., mind-wandering). While this body of research points to an increased susceptibility to distracters with increased age, other research suggests that in fact a negative correlation exists between age and task-unrelated thought (mind-wandering) during a vigilance task (Giambra, 1989) and a simple prospective memory task (Einstein & Mcdaniel, 1997).

Furthermore in a recent study that aimed to replicate Reason's diary studies, Jonsdottir, Adolfsdottir, Cortez, Gunnarsdottir and Gustafsdottir (2007) found that in addition to replicating most of Reason's findings, they also noted a negative correlation between age and reported action slips. Therefore, while it could certainly be true that older adults are less able to suppress externally distracting information, it appears that they are also better able to inhibit internal distractions like task-unrelated mind-wandering and that this may be reflected in a decreased likelihood to make action slips in everyday life. In fact, if slips are indeed the price of automatization, where Norman and Shallice's (1986) CS fails to appropriately allocate attention to handling unexpected information about a routine task, it is possible that the observed decline in older adults' ability to suppress extraneous information (Hasher et al, 1991) may actually work in their favor – potentially protecting them from missing important information that might have led to an action slip.

Distractions and the Simon Effect.

Importantly too, a body of evidence suggests that the probability of an action slip is not just about whether a distracter is present in the environment or not, but also that the actual physical location of that distracter is involved in predicting the likelihood of errors. Simon and Berbaum (1990) describe an effect wherein participants are quicker and more accurate when responding to targets whose physical location is compatible with the physical location of the stimulus/cue that instructed the movement. This effect is referred to by some as the Simon Effect (Simon & Berbaum, 1990) and by others as stimulus-response compatibility (Weigand & Wascher, 2005).

Presumably, this effect indicates that the physical location of a stimulus influences response selection such that attention is drawn to the source of the stimulus. This allocation of attention can be considered facilitative for accurate movement when the stimulus occurs in a location that is compatible with the response (i.e. the cue/stimulus appears on the right and the desired movement is to the right). However, when the stimulus and the desired response are incompatible, the Simon effect suggests that a movement to the target will be slower and perhaps less accurate.

Errors and Speed.

Even though a fair amount of debate exists in the literature regarding the possible predictors of action slips (boredom, sleepiness, divided attention, distracters…) literature on speed-accuracy tradeoffs in both older and younger adult samples suggests that any type of error should be most prevalent when moving through a task quickly. Speaking specifically to an effect of healthy aging, Salthouse (1979) discovered that older adults typically favor accuracy over speed in self-paced tasks while younger adult participants tend to prefer to finish tasks quickly despite sacrificing some accuracy for that goal.

Measuring Attention Failure

Reason's diary method of assessing action slips has already been discussed but it is important to note that it is not only his studies that have attempted to classify and quantify errors of attention in everyday routine activities. Around the same time as Reason, Broadbent was also developing a method of assessing cognitive failures and his Cognitive Failures Questionnaire, a self-report measure of one's frequency of experiencing cognitive failures in daily life (Broadbent, Cooper, FitzGerald & Parkes, 1982) correlated well with objective measures of selective attention like Tipper and Baylis' (1987) negative priming task. Though once considered an excellent measure of individual proneness to errors (Martin & Jones, 1984), the CFQ has more recently received criticisms concerning its ability to predict attention-related cognitive errors (Cheyne, Carriere & Smilek, 2006) in daily life. In their argument, Cheyne and colleagues (2006) suggest that the CFQ measures a number of underlying factors related to everyday errors, only one of which is related to attention. As a result, Cheyne and colleagues (2006) develop a self-report questionnaire that more specifically looks at errors in everyday life that are attributable to disengaged or insufficient attention. Their Attention Related Cognitive Errors Scale (ARCES) was developed from relevant items on the CFQ, questions from Reason's self-report questionnaires as well as the personal experiences of the creators. The result was a very short, twelve item, questionnaire that asks respondents to rate how often certain slips of attention happen to them in daily life on a scale from one (never) to five (very often). This measure of attention functioning in daily life was found to significantly predict attention errors as it correlates with other measures of inattention including the more objective Sustained Attention to Response Task (SART; Robertson et al, 1997).

Originally developed to investigate sustained attention and inhibition in patients with moderate to severe closed head injuries, the SART is a computer-administrated task that resembles a go-no-go paradigm. What is unique about the SART is that instead of responding to an infrequent target as would be typical in a go-no-go task, in the SART participants are actually required to respond to most items and are asked to inhibit their response to target items. While focusing attention on a tedious task such as the SART was found to be difficult to even the most vigilant participant, unsurprisingly Robertson and colleagues (1997) confirmed that patients with closed head injury found the task even more challenging. The fact that even the healthy control participants had difficulty with the task suggested that this measure might be a good one for assessing errors of attention even in a healthy population and that one's ability to avoid making errors on the SART is a reflection of one's ability to maintain consciously controlled, or sustained, attention even in very routine tasks.

Other laboratory-based tasks have been developed to assess errors of attention that occur in everyday, routine tasks. For example, the Naturalistic Action Task (NAT; Schwartz, Segal, Veramonti, Ferraro & Buxbaum, 2002) is a standardized task that asks participants to complete tasks of everyday life like wrapping a present, packing a lunch and preparing a cup of coffee. While on the surface, this task seems quite appealing given its apparent ecological validity, Giovannetti, Schwartz and Buxbaum (2007) concede that it is only effective at creating conditions under which errors will be made in impaired samples (head injury, Alzheimers, executive dysfunction), not in healthy controls.

Furthermore, while advantages of subjective reports certainly exist, measures like diary studies (Reason, 1977; 1979; 1984; Reason & Mycielska, 1982; Jonsdottier et al, 2007) and the ARCES (Cheyne, Carriere & Smilek, 2006) are also accompanied by definite disadvantages like being incomplete and sometimes even inaccurate. On the other hand, objective means of investigating action slips are also difficult at best since balancing ecological validity with rigorous methods is challenging while still actually inducing relatively rare action slips. Despite this though, developing effective methods of investigating action slips is important, primarily because of what they can tell us about the underlying mechanisms and processes that govern attention but also because of how they can help us to increase our awareness of what triggers slips, thereby helping us in minimizing their sometimes devastating consequences (Robertson, 2003).

The Slip Induction Task

The Slip Induction Task (SIT) was developed by Clark, Parakh, Smilek and Roy (in preparation) to address some of the challenges that are outlined above. Because elements of the task actually induce action slips within the laboratory, the study of these errors does not rely on rare, and potentially flawed, recollections of events, but still maintains a level of ecological validity as errors are induced with a sequence of routine actions. As a performance-based method, the SIT was developed to test theories of the impact of distracters, the spatial location of those distracters, task experience and automatization all within one computer-administrated task.

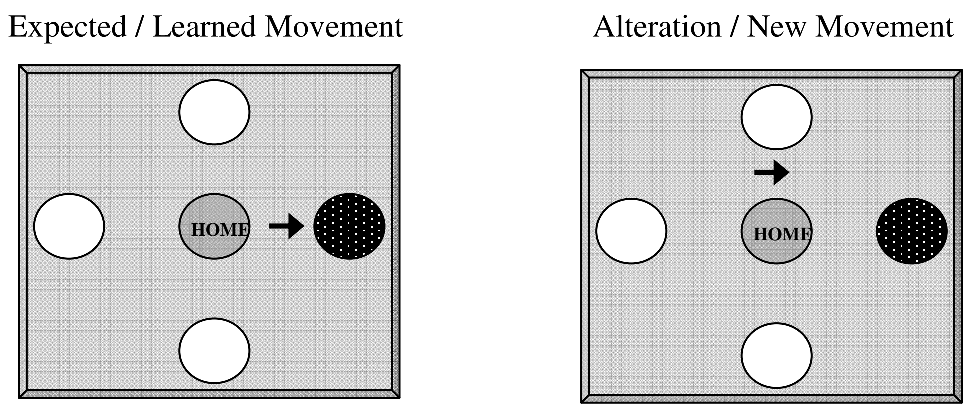
The SIT elicits slips of action by first teaching participants a series of hand movements to target buttons until the sequence became highly practiced. Following that learning phase, participants are then occasionally required to deviate from that well-learned movement routine. To accomplish this, participants are asked to learn a single sequence of seven right-hand movements to four target buttons located around a central home button. To teach the participants the movement sequence, arrow cues are visually presented either above, below, to the right or to the left of the central button. Also, during the learning phase of the task, the arrows always point toward the spatially congruent target button. Therefore, for each of the seven movements within the sequence, participants receive both congruent exogenous, the physical location of the cue, and congruent endogenous, the pointed direction of the cue, information about the target location.

After an action plan is established through extensive practice, and presumably very little attention is required to complete the sequence, participants enter the alteration phase of the SIT. During this phase of the task, participants continue to execute the same sequence of movements for an additional 5 blocks of 120 trials. Critically, in a portion of those sequences (24%), one of the seven cues violates the learned routine as the cue either appears in an unexpected spatial location only, points in an unexpected direction only or its both located somewhere unexpected and points to an unexpected target button.

Alterations

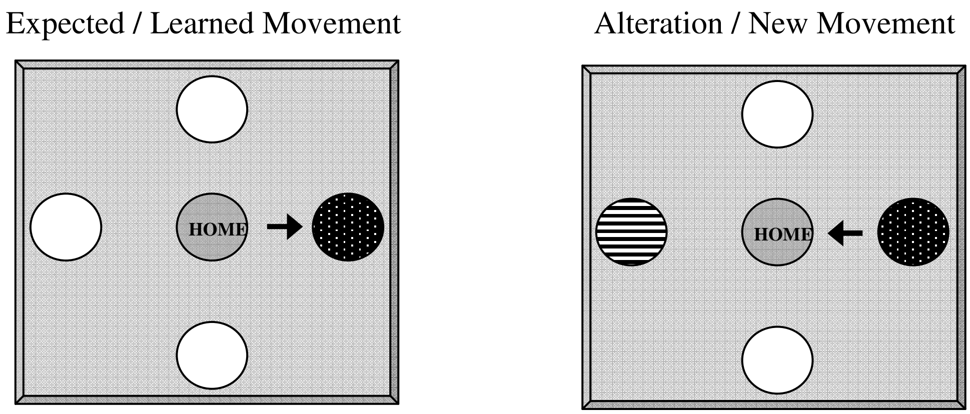
Type I: Positional Alteration (Figure 1.1) - For this type of alteration the expected goal of the movement remains as practiced however, the spatial *position* of the cue is changed. As such, for positional alterations, when a participant expects to see an arrow located to the right indicating a movement to the right target button, he/she actually sees an arrow pointed to the right but located either above, below or to the left of the central home button. Therefore, in the case of a positional alteration, the only aspect of the sequence that is unexpected is the exogenous information communicated by the spatial positioning of the cue. This alteration creates a spatial incompatibility between the location of the cue (stimulus) and the desired response and it is possible that attention will be drawn toward the cue location creating an action slip.

Figure 1.1: A Positional Alteration



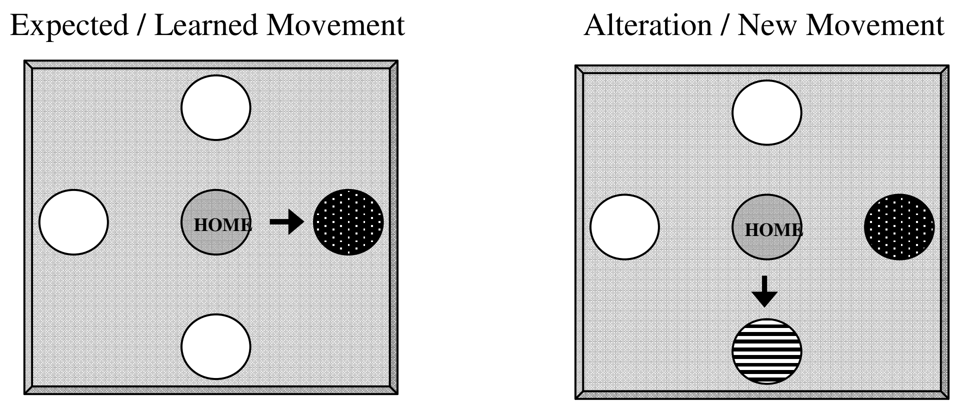
Type II: Directional Alteration (Figure 1.2) - Directional alterations involve the spatial position of the arrow cue remaining as practiced and the actual *direction* of the arrowhead being unexpected. Therefore, the actual goal of the movement is altered. This means that when a participant expects to see a cue located to the right indicating a movement to the right target, he/she actually sees an arrow pointed up, down or to the left, but yet still located to the right of the central home button, the expected spatial position. Consequently, this type of alteration only manipulates the endogenous information that the participants receive. Therefore, even though the Simon effect predicts that the spatial location of the cue should draw participants' attention toward the expected target location, this tendency must be overcome for correct completion of the movement.

Figure 1.2: A Directional Alteration



Type III: Combined Alterations (Figure 1.3) – In the case of a combined alteration, both the endogenous and exogenous information that the participant receives violates expectancy for that point in the movement sequence. Thus, both the spatial position of the cue and the pointed direction of the arrowhead are different from what a participant expects. As such, for combined alterations, even though a participant may expect a cue to appear on the right, pointed to the right target, the cue actually may appear in any one of the other spatial locations and be pointed to any one of the other targets. This alteration creates an incompatibility between the actual cue location and the expected target that may actually help draw attention away from the expected movement goal.

Figure 1.3: A Combined Alteration

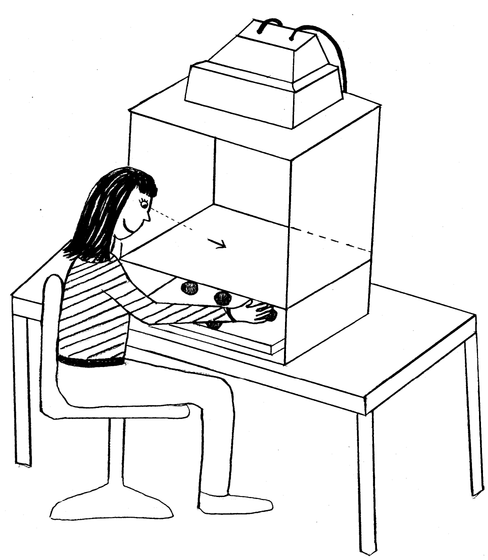


These alterations to the routine sequence were designed to directly assess the impact of distractions, task changes and critical decision points on the induction of action slips. Even though they may seem relatively straightforward, the alteration to the routine task were developed to be quite complex and based on findings with the NAT (Schwartz, Segal, Veramonti, Ferraro & Buxbaum, 2002; Giovannetti, Schwartz & Buxbaum, 2007) it was clear that this level of complexity was required. Since healthy participants have many attention resources available, tasks that aim to induce errors as a result of poor SAS – CS interactions during a routine task must involve changes in goals, external distracters and opportunities for internal distractions that are particularly challenging.

Stimuli and Apparatus

The SIT task was developed using Micro Experiments Laboratory (MEL 2.0; studies discussed in Chapters 3 and 5) and EPrime (studies discussed in Chapters 2 and 4). The sequence of cues was shown on a 15 inch flat-screen monitor that was inverted to allow the stimuli to be projected onto a mirror that occluded the participant's view of his/her hands (Figure 1.4). Situated under the mirror was a 16 inch by 16 inch button board equipped with five, 2 inch diameter buttons, one located centrally with the others located to the north, south, east and west of the central home button. Participants were always seated directly in front of the apparatus at a distance where the tip of their fingers brushed the back of the apparatus and all five buttons were within easy reach. This distance was typically between 25 and 35 centimeters from the participant's eyes to the center of the mirror. Each of the arrow cues measured 70 mm in length (creating a visual angle of between 11° and 16°), and 50 mm in height (creating a visual angle of between 9° and 13°), and they were displayed 125 mm from the center of the screen in one of the four directions.

Figure 1.4: The SIT Apparatus



Measures in the Slip Induction Task.

At the beginning of each sequence, a fixation cross appeared in the center of the screen. This fixation cross remained for a randomly variable time period of between 500 ms and 1500 ms to ensure that the participant was not able to predict when the sequence of arrow cues was about to begin. Once the fixation cross disappeared, the participant pressed the central home button, which automatically triggered the onset of the first arrow cue. Upon seeing this arrow cue, the participant released the home button and quickly moved to the target that it pointed to. At the release of the home button the participant's initiation time (IT) was recorded and this also triggered the beginning of the movement time measure. Once reaching the target, participants quickly pressed the target button and this signaled the end of the movement time (MT). Subsequently, the target button was released and the participant immediately returned to the central home button. The time that elapsed between the release of the target button and the next depression of the home button was also recorded and this measure will herein be referred to as 'return to home' (RtH) time. In addition to IT, MT and RtH time, the overall time that it took to complete each sequence (sequence time, ST) was also recorded as was the participants' overall accuracy.

<u>Effectiveness of the Slip Induction Task.</u>

Clark, Parakh, Smilek and Roy (in preparation) have demonstrated that the SIT is an effective, reliable tool for inducing action slips within a routine task. While it was found that all three alteration types were successful in eliciting slips, Clark and colleagues (in prep) found that for young adults, slips were most likely to occur when the expected movement goal was changed. In fact, cues that occurred in spatially unexpected locations only (positional alteration, 93% accuracy) produced the fewest number of action slips, while cues that required an unexpected change in task goal but remained in the expected spatial location (directional alterations, 23% accuracy) were most likely to elicit a slip of action.

These fairly frequent action errors suggest that participants were often unable to disengage their expected movement plan, primarily controlled by the CS, perhaps because the cues were considered unnecessary and were therefore suppressed, and this made them vulnerable to errors. This was particularly the case when directional alterations were encountered, indicating that when participants were operating mainly under the control of the contention scheduling system, participants were drawn toward the expected target location because of the exogenously salient cue instead of correctly moving to where the new cue information directed them (another target location).

This effect of alterations on action slips was not exacerbated by amount of experience with the task during the learning phase however as participants who practiced the task 120 times in the learning phase did not make significantly fewer errors than those with more (360 or 720 trials) practice. Given the consensus in the literature that slips are the result of automatization of actions, and that automatization is largely the result of practice, this lack of an effect was surprising. The authors have suggested that perhaps the range of practice amount was not appropriate for the task, that either many fewer, or many more practice trials would be required to show evidence of an effect. Indeed, Giovannetti and colleagues (2007) have shown routinization in as few as 10 trials and Nissen and Bullemer (1987) have indicated automatization is only achieved after several thousand repetitions.

General Objectives of this Collection of Studies.

This collection of studies was designed to learn more about how well pre-existing theories of how and why slips of action occur explain the action slips that are induced with the SIT. By designing studies that allowed for the manipulation of task pace and task goals we are able to assess the impact of healthy aging, inhibition/suppression of irrelevant information and pace of task in the induction of action slips.

In Chapter 2, we attempt to replicate Clark, Parakh, Smilek and Roy's (in preparation) study and expand it to also determine if one's likelihood of making an error on the SIT correlates with other measures of inattention, namely the SART (Robertson et al, 1997) and the ARCES (Cheyne, Carriere & Smilek, 2006). Also, given Norman and Shallice's model of action (1986; 2000) we expected that avoiding an action slip requires a switch between the CS and the SAS at an appropriate time. As such, an additional goal of this study was to determine how accuracy on the SIT relates to a variety of measurements of task timing. To determine this, measures of IT, MT and overall time to complete the sequence (ST) for movements in which unexpected cue information was encountered were considered. Finally, in an effort to determine if amount of experience with the sequence during the learning phase impacts likelihood of making a slip, the study discussed in Chapter 2 includes a group where participants had significantly less exposure to the sequence (20 as opposed to 360 trials) and the differences between this group's accuracy and the accuracy for those who had more practice will be discussed.

In Chapter 3 the SIT performance of a sample of healthy older adults is described. The overall purpose of this study was to address the inconsistency that exists in the literature regarding whether older adults' are more or less likely to make action slips compared to young adults. One hypothesis is that older adults' inability to suppress distracting information (Hasher, Stolzfus, Zacks & Rypma, 1991) would be related to increased propensity to make action slips on the SIT. Conversely however, other data suggesting that older adults are less likely to be internally distracted and less prone to attentional errors in everyday life (Giambra, 1989) would actually suggest that older adults would be more accurate on the SIT than younger adults from previous studies (Clark, Parakh, Smilek & Roy, in preparation; participants from Chapter 2).

Based on results that were found when studying older adult performance on the SIT, Chapter 4 presents a study in which participants were asked to slow their task pace to a range which was seen in older adults. By providing these young adult participants with feedback following each trial, they were encouraged to complete each sequence in five to seven seconds and we predicted that this would be a significantly slower speed than has been observed in participants who were able to do the task at their own pace. Given literature on speed accuracy trade-offs, we expected these slower-paced participants to achieve higher accuracy scores than what was seen in Clark, Parakh, Smilek and Roy (in preparation) and in Chapter 2 but it was unclear whether their suppression skills would help or hinder them compared to the older adults from Chapter 3.

Finally, as discussed in Chapter 5, the role of suppression of cues in the SIT was directly manipulated in that participants in this study were told to ignore any cues that violated their expectations. As such, it was in the participants' best interest to always suppress the arrow cues since they were unnecessary for guiding movement. We predicted that if young adults were unable to suppress the unexpected cues, participants would make as many if not more errors than has been reported for the original version of the SIT (Clark, Parakh, Smilek & Roy, in preparation). Conversely however, based on the negative priming literature (Tipper & Cranston 1985; Hasher, Stoltzfus, Zacks & Rypma, 1991), it was likely that participants would have no difficulty in successfully suppressing/ignoring the irrelevant, distracting cues and as such would make little to no errors compared to what has been reported with the original version of the task.

CHAPTER TWO: Inducing Slips of Action with Healthy Young Adults

OVERVIEW

Errors of attention, or slips of action, are common occurrences; perhaps you walk into a room and are unsure of what you went there to do, or maybe you fail to make a left hand turn while driving due to a cell phone interruption. While many of these attention errors are simple nuisances, action slips can have damaging consequences. Past research has suggested that action slips are likely to occur in familiar environments (Reason & Mycielska, 1982) while executing overly routine tasks (Norman & Shallice, 1986) because attention resources are not actively engaged (Robertson et al, 1997). This study was designed to replicate previous findings from Clark, Parakh, Smilek and Roy (in preparation) in which slips of action were induced during the execution of a well-learned task. Thirty-three young adults (18 – 25 years of age) were instructed to complete a well learned action sequence as quickly and accurately as possible and action slips were induced by occasionally requiring deviations from the learned routine by either changing the physical cue location or by changing one of the actual movement goals within the sequence. As predicted, slips were most prevalent when unexpected cue information required participants to adjust their expected movement goal. Furthermore, when participants were able to make these adjustments and avoid an action slip this was accompanied by a cost in the time required to complete the movement. These results suggest that the Slip Induction Task is able to reliably induce slips of action and that the design of the task contributes unique information about the micro-structure of an action slip, specifically the timing of an error, which may be beneficial in designing methods of preventing these types of errors.

INTRODUCTION

At almost all waking hours we are able to perform a number of complex activities with extreme ease because those activities have become highly practiced and routine. Consider for example, making a morning coffee, driving on a busy highway on the way to work or operating a daily-used computer program. Usually we perform these tasks effortlessly, with very little conscious attention, but unfortunately, errors in these well-learned tasks do occur relatively frequently. Errors of routine tasks, or slips of action, are frustrating, distracting, costly and at times, physically dangerous (Robertson, 2003).

Considering the pervasiveness of slips of action in daily life it might be surprising that the bulk of research in this area was conducted several decades ago and even has mostly been limited to studies of subjective reports from participant diaries (Reason, 1977, 1979, 1984, Reason & Mycielska, 1982; Jonsdottir, Adolfsdottir, Cortez, Gunnarsdottir & Gustafsdottir, 2007). These diary studies suggest that slips of action are highly related to one's experience with the task at hand and frequently occur at points of time where a decision must be made about how to proceed with the steps of the task. Reason (1979) theorized that it was at these junctures or decision points where participants had to access information about the goals of the tasks and what actions had been done up to that point to achieve those goals.

Later findings by Shallice and Burgess (1993) and Norman and Shallice (2000) have complemented Reason's research by suggesting the existence of two independent systems that help to control the limited resource that is attention control. The first, the contention scheduling system, directs well-learned actions, operates mainly outside of conscious control and therefore requires very few attention resources. Conversely, their supervisory attention system requires consciously controlled attention to allow for the execution of novel or dangerous tasks. Inherent in their model is the assumption that for accurate action production and efficient attention control, people must switch between these two systems at optimal times, like when the goals of a task change.

Taken together, Reason and Norman and Shallice's work suggests that slips of action result from a failure to adequately interrupt the functioning of the contention scheduling system when required and thus is likely the penalty for the automization that comes along with one's experience with a task. Research has also suggested that one's propensity to commit errors of this sort can be exacerbated by internal distracters like worry and/or boredom (Manly, Lewis, Robertson, Watson & Datta, 2002 and Wallace, Vodanovich & Restino, 2003), divided attention requirements (Botvinick & Bylsma, 2005; Giovannetti, Schwartz & Buxbaum, 2007; Humphreys, Forde & Francis, 2000) and external distracters within the task environment (Buxbaum, Schwartz & Montgomery, 1998).

More recently, Clark, Parakh, Smilek and Roy (in preparation) have developed the Slip Induction Task (SIT) in which slips of action are induced within a laboratory environment by requiring occasional deviations from a well-learned action sequence. With this task they have demonstrated that action slips are likely to occur when unexpected cue information is encountered. Cues that occurred in spatially unexpected locations produced the fewest number of action slips, while cues that required an unexpected change in task goal but remained in the expected spatial location were most likely to elicit a slip of action. In these fairly frequent instances, Clark, Parakh, Smilek and Roy (in preparation) suggest that participants operated mainly under the control of the contention scheduling system and as such were drawn toward the expected target location because of the exogenously salient cue instead of correctly moving to where the new cue information directed them (another target location).

This experiment was designed to determine if the results described above could be replicated and furthermore if the propensity to make errors on the SIT correlates with errors on other measures of inattention, namely the Sustained Attention to Response Task (SART; Robertson et al, 1997) and the Attention Related Cognitive Errors Scale (ARCES; Cheyne, Carriere & Smilek, 2006). As such, we hypothesized that the SIT would successfully induce slips of action most frequently when unexpected arrow cue information required a change from the expected movement goal and least frequently when the arrow cue acted as an external distracter only. In addition, we expected that participants who make more errors on the SIT would also make more errors on the SART, where participants must withhold their response to an infrequent target, as well as self-report more frequent errors of attention in everyday life as measured by the ARCES questionnaire.

An additional goal of this study was to determine how accuracy on the SIT relates to a variety of measurements of task timing. We expected that there would be costs associated with switching between the contention scheduling system and the supervisory attention system. We anticipated that these switching costs would be evident when considering the timing structure of movements in which unexpected cue information was encountered. Consequently, we predicted that participants who complete the task at a faster pace will make more errors when they encounter unexpected arrow cues since the supervisory system will have less time to interrupt the contention scheduling system when required. On the other hand, participants who are moving more slowly throughout the task will have increased accuracy since more time is available for the switching between the two attention control systems.

Finally, we were also interested in learning if one's likelihood of making an action slip in the SIT is affected by more experience, or practice, with the task. Based on Reason's studies (1977, 1979) it is logical to predict that participants who have increased exposure to the movement sequence in the form of additional practice trials will be more prone to action slips. This is probable as increased practice of the task should make it more routine and thus, more likely to be controlled with the contention scheduling system (Norman & Shallice, 1986) which is not well-equipped to handle unexpected changes in the routine.

METHOD

Participants.

Thirty-three, right-handed, undergraduate students volunteered to participate in this experiment from a list of studies that were being conducted on campus at the University of Waterloo. All were between 18 and 25 years of age, had normal or corrected-to-normal vision and hearing, were healthy with no history of neurological injury or impairment and received course credit as compensation for their time.

Experimental Design and Procedure.

Participants began the experiment by first completing the 12-item self-report ARCES questionnaire in which participants rated, on a scale of one to five, how often they experience failures of attention in daily life. Subsequently, the SART task was completed, following which participants proceeded to the SIT where slips of action are induced by requiring occasional deviations from a well-learned action routine.

In the SIT, participants were first taught a sequence of seven hand movements to target buttons by following arrow cues that were spatially congruent with the pointed direction of the cue. The arrow cues measured 70 mm in length (creating a visual angle of between 11° and 16°), and 50 mm in height (creating a visual angle of between 9° and 13°) and were displayed 125 mm from the center of the screen in one of four directions. The four target buttons were each 2 inches in diameter and were arranged above, below, to the right and to the left of a central home button on a response board. Each sequence began with a fixation cross which remained for a variable period of 500 to 1500 milliseconds and participants were instructed to press the central home button as soon as they noticed that the fixation cross disappeared. Upon depression of the central home button, the first arrow cue was triggered (begins initiation time, IT, measure) and participants released the home button (ends IT measure, begins movement time, MT, measure). Participants then moved to and quickly pressed the corresponding target button (ends MT measure, begins return to home time, RTH, measure) and then returned to the central home button where upon depression (ends RTH measure), the next arrow cue was triggered. The time to complete an entire sequence of 7 movements to target buttons was termed sequence time, ST.

To ascertain whether amount of experience with the base sequence of movements affects one's likelihood of making action slips, participants were randomly assigned to practice the exact same movement sequence either 20, 120 or 360 times and all were instructed to move as quickly but as accurately as possible to the target button that corresponded with the arrow cue that appeared. Upon completion of the learning phase of the SIT, participants immediately proceeded to the alteration phase of the experiment. In this portion of the task, participants executed the movement sequence an additional 600 times and while the sequence remained as learned the majority of the time, 24% of the trials contained one unexpected (altered) arrow cue. This unexpected arrow cue could occur either at the beginning of the sequence, on movement two or three, or at the end of the sequence, on movement five or six. Furthermore, forty-eight of the altered arrow cues were unexpected because they occurred in an unexpected physical location only (a positional alteration; see description in Chapter One, Figure 1.1, p.19), another forty-eight were pointed to an unexpected target only (a directional alteration; see description in Chapter One, Figure 1.2, p.20), and the other forty-eight occurred in both an unexpected location and was pointing to an unexpected target (a combined alteration, see description in Chapter One, Figure 1.3, p.21). Prior to beginning this alteration phase, participants were told that they would occasionally encounter unexpected arrow cue information and if they did, they were to move to the target button that the arrow pointed to, even if that was not what they had practiced during the learning phase. In addition, for the first few trials in both the learning and alteration phases the experimenter observed the participants' movements to ensure that the instructions were understood and answered participant questions while actually experiencing the protocol.

Analyses.

Timing data points were excluded from analyses if they fell outside a pre-determined range. This range was identified first by what should be logical for that timing measure (i.e., a movement to a target less than 15 cm away should not require more than five seconds) and also by what the normal distribution of scores were for that measure (i.e., any amount of time that was more than two standard deviations away from the mean). As such, any individual ST that fell outside the range of 2000 and 10000 ms, or MT that fell outside the range of 40 and 2000 ms was excluded from that participant's average. In total, for all 33 participants, only four (0.02%) MTs and only 63 (0.3%) STs were longer than would be normal and logical and zero MTs or STs were shorter than the allowed range. With respect to IT data, we also excluded data points that fell outside a normal, logical range. ITs that were less than 40 ms were excluded as they most likely represented an anticipation to move, rather than an actual reaction to the cue. These instances were rare however as only 2% of IT data points for altered trials were excluded from analyses. It was also possible for an IT point to be excluded because it was too slow, but this only occurred on 0.2% of trials.

Further exclusion was possible if a participant's *average* accuracy, ST, IT or MT on a positionally, directionally or combined altered trial was two standard deviations above or below the mean for the practice group which they were a part of, that data point was excluded from all analyses as it was considered an outlier from the group. These criteria led to the exclusion of 3% of the data points for positionally altered trials, less than 2% of the data points for directionally altered trials and zero data points from the combined altered trials.

Performance during Learning phase.

As an indicator of how increased practice of the sequence during the learning phase impacts time to complete the sequence (ST) and errors, separate between-subjects univariate ANOVAs with corresponding Tukey's b post-hoc analyses were used to compare STs and errors for the 20 trials of practice for those who repeated the sequence only 20 times, and the final 20 trials of practice for those who repeated the sequence 120 or 360 times.

Task Experience, Accuracy and Speed.

With an overall goal of determining if the amount of practice during the learning phase had an impact on accuracy in the alteration phase, we first used a one-way ANOVA to examine whether experience with the task was reflected in the ST timing measure. Subsequently, a three (practice group, between subjects variable) by four (alteration type, within subjects variable) mixed model ANOVA was used to determine if any or all of the alteration types used in the SIT were successful in provoking action slips and whether the tendency to make a slip increased with the amount of experience that participants had with the sequence during the practice phase. Consequently, accuracy on trials in which a positional, directional or combined cue alteration occurred was computed and three simple planned comparisons were made between each of these alteration conditions and accuracy on trials in which no alteration to the sequence occurred. In addition, three pair-wise t-tests, with corresponding Bonferoni α-level corrections were planned to statistically compare accuracies between the positional, directional and combined conditions.

Timing of an Error.

A unique characteristic of the SIT is the inherent ability to consider the timing micro-structure that contributes to an error or correctly completed trial. Using these measures, separate repeated measures ANOVAs were completed for each of the timing measures (MT, IT and ST) where two simple planned contrasts were used to compare timing on altered trials in which an error/slip was made (level 1) and altered trials that were completed correctly (level 2) to unaltered trials (level 3). In addition, one t-test was required for each of timing measures (MT, IT and ST) to directly compare timing on altered trials where an error was made (level 1) to altered trials which were completed correctly (level 2).

Speed Correlations.

To determine if the general pace at which participants completed the task was related to accurate performance, a series of Pearson correlations were conducted between errors on altered trials, accuracy on the three types of altered trials, unaltered ST and altered ST. In addition, using a step-wise multiple regression unaltered ST, altered ST and practice amount were tested for their ability to explain variance in participants' errors on altered trials.

Performance on Other Attention Measures.

Finally, to establish the SIT as a valid measure of attention failure, correlations between errors on the SIT, commission errors on the SART and self-reported errors in daily life as measured by the ARCES were also considered.

RESULTS

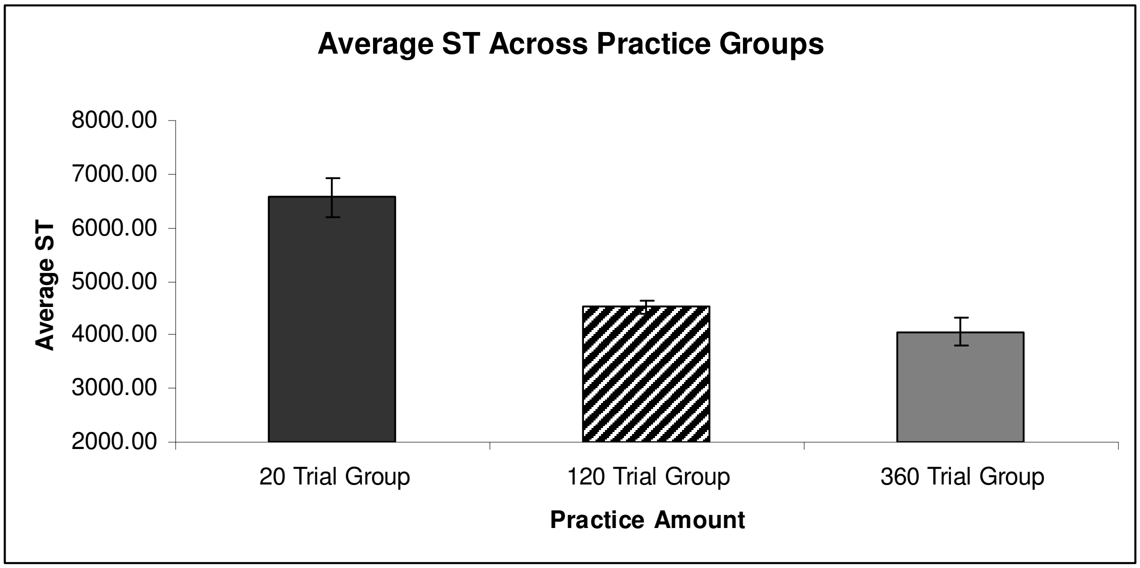
Learning Phase Analyses

Increased experience with the movement sequence, in the form of additional repetitions, led to an overall decrease in time required to complete the seven movements during the final 20 sequences of the learning phase ($F(2,30) = 16.911$, $p<0.001$, Table 2.1, Figure 2.1). Further, Tukey's b post-hoc analyses reveal that this effect is associated with only a significant decrease in ST for participants who repeated the sequence 120 or 360 times compared to those who practiced the sequence 20 times. There were no significant differences in ST between the 120 trial and 360 trial groups. In addition, there was no significant impact of practice amount on the number of incorrect movements during the final 20 sequences of the learning phase (see Table 2.1).

Table 2.1: Descriptive Statistics for Learning Phase Data

	ST (in ms) During Last 20 Practice Trials		Errors During Last 20 Practice Trials	
	Mean	SD	Mean	SD
20 Practice Trials	6570.28	1195.31	0.45	0.93
120 Practice Trials	4520.76	1179.44	2.44	1.94
360 Practice Trials	4063.38	938.78	1.54	3.37

Figure 2.1: Comparing Practice Groups on Average Time to Complete Sequence (ST, in ms) During Final 20 Trials of Learning



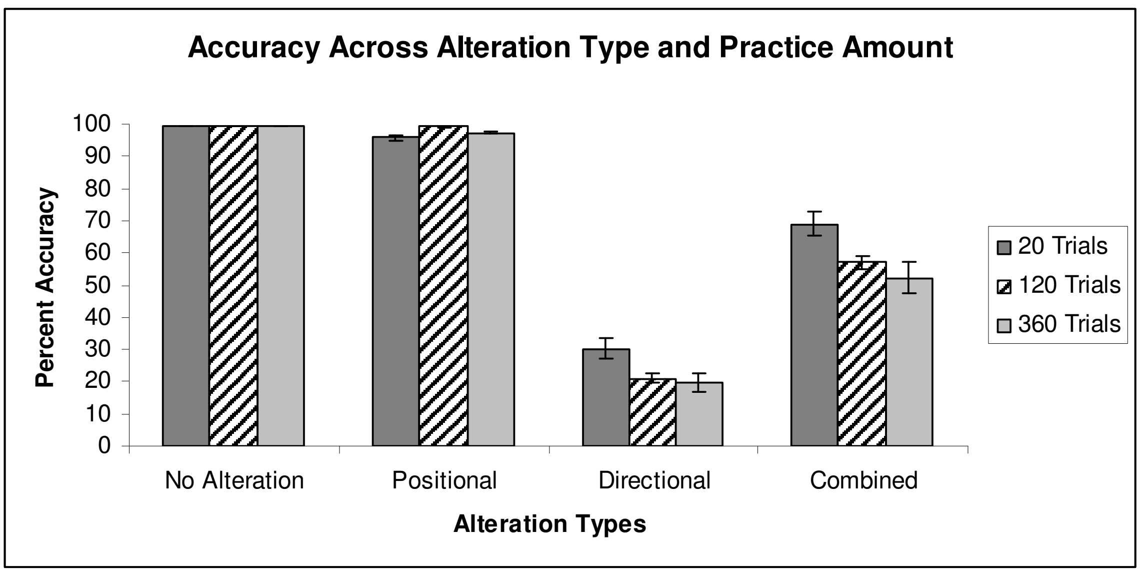
<u>Alteration Phase Analyses</u>

As hypothesized our analyses revealed a main effect of alteration type on accuracy ($F(3,24) = 249.43$, $p<0.001$, see Table 2.2 for descriptive statistics) such that slips of action were most prevalent when unexpected arrow cue information required a change from the expected movement goal (See Figure 2.2), as is found in directional and combined alterations compared to unaltered trials ($F(1,24) = 718.52$, $p<0.001$, $F(1,24) = 92.71$, $p<0.001$, respectively). Further, while still significantly different from unaltered trials, the fewest slips were induced when the unexpected arrow cue acted as an external distracter only, as is the case for positional alterations ($F (1,24) = 13.664$, $p=0.001$). These results replicate Clark, Parakh, Smilek and Roy's (in preparation) findings where directional alterations were most detrimental to performance and positional alterations were least likely to induce a slip. However, type of alteration did not significantly interact with practice amount during the learning phase (F (6,72) = 1.591, p=0.162), nor was there a main effect of practice on accuracy (F (2,24) = 1.631, p=0.251).

Table 2.2: Descriptive Statistics for Accuracy Data during Alteration Phase

	Unaltered Accuracy		Positional Accuracy		Directional Accuracy		Combined Accuracy		Total Errors: Altered Trials	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
20 Trials	99.64	0.29	95.72	4.11	30.23	16.01	69.03	18.62	48.00	13.59
120 Trials	99.66	0.23	99.22	1.22	20.89	7.24	56.99	11.72	61.78	11.33
360 Trials	99.55	0.44	97.37	2.64	19.52	15.05	52.77	24.50	63.15	18.36

Figure 2.2: Accuracy Data during Alteration Phase

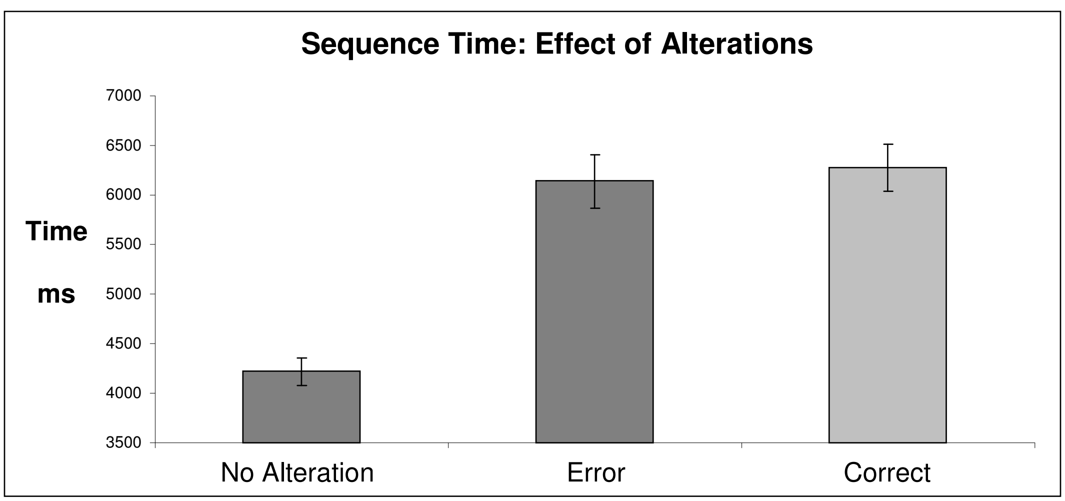


Additionally, as can be seen in Figure 2.3, whenever participants encountered unexpected arrow cue information for one of the movements within a sequence, regardless of what type of alteration it was, there was a dramatic impact on the amount of time that participants used to complete that sequence compared to when no alteration was encountered (F (2,58) = 82.86, p<0.001). This increase in time to complete the sequence occurred regardless of whether the altered movement resulted in an error or not as error STs and correct STs did not differ (F(1,29) = 3.998, p=0.067). However, upon considering the MTs and ITs, it became evident that the observed increase in ST may be due to two different processes depending on whether an error was made or not (see Table 2.3 for descriptive statistics for all timing data).

Table 2.3: Descriptive Statistics for Timing Data during Alteration Phase

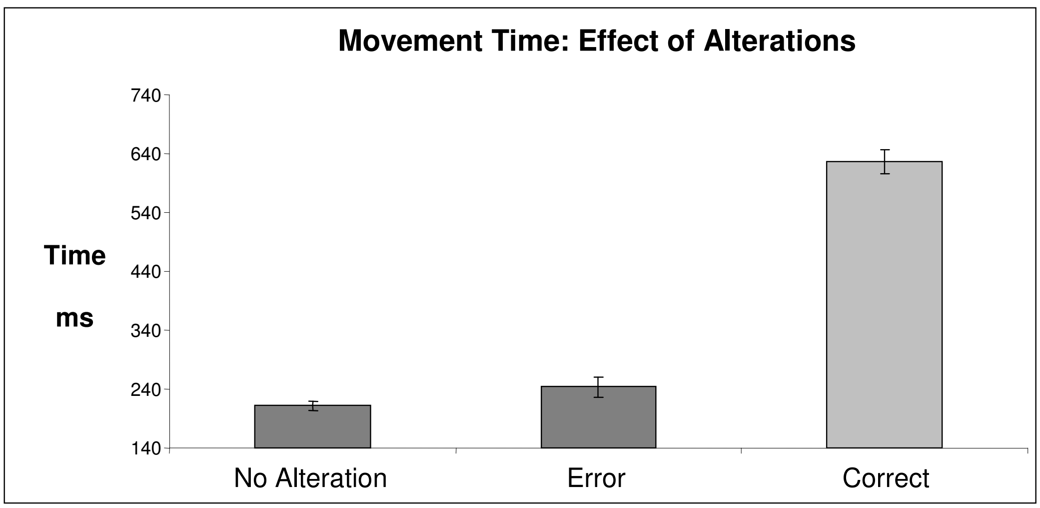
	ST (in ms)		MT (in ms)		IT (in ms)	
	Mean	SD	Mean	SD	Mean	SD
Unaltered Trials	4319.85	758.24	211.86	47.41	123.36	34.97
Altered & Error Trials	6140.86	1467.71	244.18	95.10	107.62	36.23
Altered & Correct Trials	6277.76	1323.11	626.10	107.39	126.30	43.98

Figure 2.3: Average STs (in ms) Comparing Unaltered Trials and Altered Trials that were Executed Correctly or Resulted in Errors.



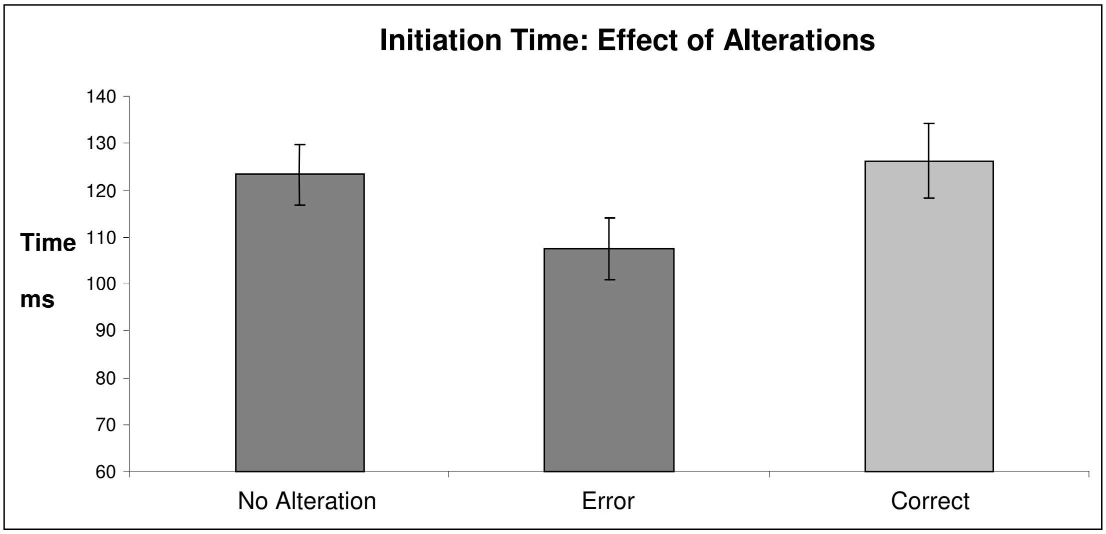
In fact, whenever a participant encountered an altered cue but was able to perform the movement correctly, that is, was able to reconcile the unexpected cue information with their expected movement plan, there is a considerable cost to the amount of time required to move to that target (MT) compared to trials in which an error is made, $F(1,29) = 380.80$, $p<0.001$, and trials in which no alteration occurred, $F(1,29) = 593.36$, p<0,001 (See Figure 2.4).

Figure 2.4: Average MTs (in ms) Comparing Unaltered Trials and Altered Trials that were Executed Correctly or Resulted in Errors.



Interestingly though, no difference between ITs on correctly executed and unaltered trials is observed ($F(1,29) = 0.315$, $p=0.57$, see Figure 2.5). However, IT data does suggest that participants responded more quickly to arrow cues on trials where an error would subsequently be made than when that altered trial would be completed correctly ($F(1,29) = 12.593$, $p=0.001$) or no alteration was encountered ($t(29) = -8.277$, $p<0.001$).

Figure 2.5: Average ITs (in ms) Comparing Unaltered Trials and Altered Trials that were Executed Correctly or Resulted in Errors.



Correlation data provides further evidence that the speed at which the task was completed is related to participants' performance on the SIT. Indeed, as described in Table 2.4, significant correlations were found between average ST of unaltered trials and accuracy for trials that contained a positional, directional and combined alteration as well as the overall number of errors that were made on all altered trials combined. Similarly, increases in both unaltered and altered ST (slower performance) significantly predicted increased accuracy when directional and combined alterations were encountered and interestingly, a generally slower pace, as measured by unaltered ST, negatively correlated with accuracy of positionally altered trials.

Table 2.4: Correlations between Speed of Task and Errors/Accuracy

	Unaltered ST	Altered ST
Altered Errors	**r = -0.759, p<0.001**	**r = -0.550, p=0.001**
Positional Accuracy	**r = -0.381, p=0.04**	r = -0.225, p=0.216
Directional Accuracy	**r = 0.740, p<0.001**	**r = 0.500, p=0.003**
Combined Accuracy	**r = 0.774, p<0.001**	**r = 0.586, p=0.001**

Finally, when considering the correspondence between the SIT and other measures of inattention (see Table 2.5), we found that errors on altered trials in the SIT were positively correlated with participants' self-reported frequency of attention failures in daily life (r = 0.378, p=0.03) however slip errors did not correlate with inhibition errors on the SART (r = 0.240, p=0,185), see Table 2.6 for ARCES and SART means and standard deviations.

Table 2.5: Correlations between the SIT and Other Measures of Inattention

	ARCES	SART Errors
Altered Errors	**r = 0.378, p=0.03**	r = 0.240, p=0.185
Unaltered Errors	r = 0.01, p=0.960	r = -0.169, p=0.380
Positional Accuracy	r = 0.126, p=0.483	r = 0.134, p=0.471
Directional Accuracy	r = -0.326, p=0.06	r = -0.191, p=0.295
Combined Accuracy	r = -0.178, p=0.337	r = -0.265, p=0.157
ARCES		r = -0.043, p=0.816

Table 2.6: Descriptive statistics for ARCES and SART

	Mean	Standard Deviation
ARCES (avg score out of 5)	2.54	0.56
SART Errors (avg score out of 25)	9.19	4.35

DISCUSSION

This research was designed to complement earlier diary study experiments within the field of action slips by testing an experimental task which attempts to induce several slips of action in a brief period of time. If effective, this laboratory task could add valuable information to the literature with respect to the likely precursors to action slips, the probable mechanisms by which the errors occur as well as shed light on what strategies might be helpful in preventing such attention-related errors. Through a series of rare manipulations to a well-practiced movement routine, the SIT attempts to elicit errors all the while allowing for the collection of valuable information about the timing of movements when such manipulations are encountered. Also, with the inclusion of additional tasks like the SART and ARCES, which are understood to reflect one's likelihood to make attention-related errors in everyday life, it may be possible to determine the extent to which performance on the SIT is correlated with attention-related performance of everyday, routine tasks.

The results of this experiment provide converging evidence to what was found by Clark, Parakh, Smilek and Roy (in preparation) such that alterations to a routine sequence of movements, like occurs in the SIT, do elicit errors within that routine. Moreover, it was observed that while all three types of manipulations to the sequence induced a significant number of errors compared to when no manipulation was present, directional alterations were most detrimental to performance, positional alterations were least likely to induce a slip and combined alterations, though more challenging than positional alterations, were easier to reconcile than directional ones. Importantly these three types of alterations differ from each other in unique ways and these distinctive characteristics, combined with the errors they produce, provide a glimpse into the anatomy of an action slip.

Both directional and combined alterations required participants to change their expected movement goal and move toward an unexpected target button. Positional alterations on the other hand, allowed participants to maintain their expected goal for accurate performance. Consequently, if a participant made an error as a result of a positional alteration they must have been distracted enough by the unexpected physical location of the arrow cue that their expected movement plan was interrupted and they moved to the target button that was spatially congruent with the unexpected cue. Given these required circumstances for a positional error, it makes sense that this type of alteration induced the fewest number of slips in all the participants.

As mentioned above, directionally altered trials involved an arrow cue that appeared in the expected physical location but the pointed direction of the cue indicated that a movement toward an unexpected target button was required for the trial to be executed correctly. Therefore, a switch from the CS to the SAS was required. So, even though participants' attention was exogenously attracted to the expected target and previous experience also drew them toward that button, all of this information needed to be overridden for accurate performance of the movement. With fewer than 30% of directionally altered trials being completed correctly, it is obvious that participants had significant difficulty initiating the required switch from the CS to the SAS to enable such an override to occur.

Combined alterations however were executed correctly almost 60% of the time, a significant improvement compared to accuracy on directionally altered trials. While these manipulations to the expected movement sequence did require a change in expected movement goal, the cues for combined alterations also appeared in an unexpected physical location. This increase in accuracy with respect to combined alterations suggests that even when a change to the routine movement goal is required, accurate performance can be enhanced by exogenously cueing that change in a physical location that is incongruent with the expected movement direction. This suggests that whenever an unexpected goal change was cued in an unexpected location, attention was drawn away from the expected target location and the switch from the 'auto-pilot' CS to the SAS was facilitated.

Interestingly, a participant's ability to complete altered movements correctly was linked to the average pace at which they completed the task. In fact, one's ability to inhibit an expected movement plan, as is required for both a directionally and combined altered trial, was positively correlated with both the general pace of task (as measured by ST of regular, unaltered trials) as well as the speed with which altered trials were completed (as measured by ST of altered trials). The correlation between general pace of task (unaltered ST) and accuracy on trials which were altered positionally was reversed however, such that performing the task more slowly overall was linked to decreased performance when the physical location of the arrow cue was unexpected and likely distracting. Therefore, other samples of participants who move more slowly throughout the SIT, which will be discussed in chapters three and four, should experience enhanced accuracy on trials in which changes in expected movement goal are required.

Taken together, these results indicate that strategies for maintaining accurate performance during the execution of routine tasks may differ depending on the type of changes to the routine that are required. If simply distracting and uninformative information is likely (positional alteration), then a slowed pace is not apt to benefit performance. Instead, moving more quickly overall may be related to a heightened ability to simply disregard the unexpected, distracting, exogenous cue information as was the case for positional alterations. However, if important, task relevant information is probable, operating at a generally slower pace is likely to improve performance. This may be because the SAS is allowed the time to more vigilantly monitor the operations of the CS or at least because a slower pace increases the likelihood of the SAS's interruption actually impacting performance at the critical decision point instead of just after an error has been made. In addition, should goal-relevant information during a routine task be probable, the improved accuracy on combined alterations within the SIT would suggest that action slips are more likely to be avoided if that goal-relevant information is exogenously salient enough to capture attention away from the routine (CS operated) and toward the new goal (SAS operated).

In addition to providing insight into the relationship between general pace of task and ability to reconcile unexpected cue information during routine actions, the precise measurements of timing within the SIT were also able to shed light on the possible points within an action when the SAS is most likely to intervene. Despite finding an overall effect of altered cue information on time to complete an entire sequence, a closer look at the timing microstructure of the movements revealed that the actual reason for that increase in ST may depend on whether an error was made or not. Whenever the SAS was successful at interrupting the CS, which presumably is necessary for the correct completion of an altered trial, this switching of attentional control was accompanied by an increase in the time that elapsed between the release of the home button and the depression of the target button, the MT phase. This increase in MT, while IT remained unchanged, likely suggests that switching between attentional control systems occurs online during the movement phase of an action and not before during the movement preparation (IT) phase. Importantly though, this lengthened MT may not only reflect the processing demands of switching between the CS and SAS.

A further possibility comes from literature on inhibition of return (IOR; Tipper, Howard & Jackson, 1997). This phenomenon could also explain some of the MT slowing that is observed, particularly when the movement is made to a previously reached for target button. When participants in this study encountered a directional or combined alteration, there was a 33% chance that the altered cue would direct their movement to the target location that they had just visited on the previous movement. Since the IOR effect suggests that a participant's reaction to a cue that indicates a movement to a previously reached for target is often slowed (typically by a magnitude of 40 ms) due to a suppression of attention to that location, it is possible that a portion of the slowing that is observed in this study is the result of this phenomenon. Further, since participants in this study did have very short ITs that are likely reflective of an anticipation to move to an expected location rather than a pure reaction to the arrow cue, this IOR effect may have been carried forward into the MT measure. Therefore, while a very small portion of the slowing that is observed with respect to MT for correctly completed, altered trials could very well be due to a suppression of attention to a previously moved to target (IOR effect), it is more likely that any one or combination of the following if more responsible for the effect: the required time to actually process that the arrow cue is unexpected, the need to inhibit the expected movement plan, the time required to program the new movement online.

On another note, participants' likelihood to commit action slips when unexpected arrow cue information was encountered in the alteration phase was not affected by the amount of practice that they had with the sequence during the learning phase, nor by the type of alteration that was encountered. This lack of a practice effect on accuracy is certainly surprising since so much research and anecdotal evidence exists that would predict increased practice leading to more frequent attention-related errors. We believe that a fundamental difference exists between errors that are induced with the SIT and action slips that occur in everyday life. This critical difference can be illustrated with the typical routine of making coffee. In everyday life it is not unheard of for a person to make several hundred cups of coffee in any given year and potentially tens of thousands in a lifetime. Within the SIT however, the highest number of repetitions in the learning phase was 360. It is probable that a very high number of repetitions is important for establishing an effect of practice within the SIT but it was impractical to include such a condition in this early stage of task development.

A further complication to finding an effect of practice within the SIT is that by the time participants were at the end of the 600 trial alteration phase, even those in the low practice condition had rehearsed the sequence 620 times. It is quite possible that this basically rendered the sequence very well-learned even for the low practice group and dramatically weakened any opportunity for finding an effect of practice on accuracy. We suggest that a future experiment should be completed where a much larger sample of participants would complete the SIT and fewer sequences during the alteration phase would be required. For example, if the alteration phase was only 25 trials and 6 of those trials contained an altered arrow cue at some point in the sequence, the integrity of the task would be maintained such that 24% of the trials would be altered but the complication of too much additional experience with the task during the alteration phase might be averted.

With respect to the relationship between accuracy on the SIT and other measures of inattention, we found that while no correlation was found between SIT errors and SART errors, performance on the SIT does moderately predicts one's propensity to make attention related errors in everyday life as measured by the ARCES. Therefore, despite a reported relationship between the SIT and SART in Clark, Parakh, Smilek and Roy (in preparation) we cannot replicate said result and as such, must conclude that likelihood of making an error on the SART does not predict one's propensity to commit an action slip on the SIT. However, when a task like the SIT becomes well-learned and one becomes challenged by requirements to inhibit either distracters or expected movement plans, one's likelihood of doing so effectively does significantly correlate with ability to avoid attention-related slips in everyday life.

CONCLUSIONS

We provide evidence in this paper that infrequent alterations to cue information during the performance of a well-learned task in a laboratory environment can elicit errors. Participants were most prone to making such errors when the unexpected cue information required participants to adjust their expected movement goal, and especially when the unexpected cue exogenously drew attention toward the expected target location. Unique to the SIT, precise timing measures provide insight into the conditions under which certain changes to the routine are more likely to induce errors. For instance, unexpected cues that require a change in movement goal were more likely to induce errors in participants who completed the task faster overall than those who operated at a slower pace. Moreover, when participants were able to reconcile unexpected cue information and move to the correct target button they needed to sacrifice speed to achieve accurate performance. Interestingly however, this shift was only evident during the movement phase of the action. This suggests that when attentional control switches to a less economical but more carefully monitored system, this switch occurs online – *during* the movement and after one has initiated a movement to a cue.

CHAPTER THREE: Older and Wiser? The Impact of Age on Slips of Action

OVERVIEW

Senior's moments – Often simply an annoyance, these are seemingly harmless everyday attention errors but they can manifest themselves in very dangerous ways, resulting in accidents or injuries. Senior moments, or slips of action, presumably get their name because we assume that their occurrence increases with and becomes exacerbated by age. In this study, we aimed to examine this widely held assumption. Studying twenty-five healthy, older adults we looked specifically how often they report experiencing failures of attention in everyday life by administering the Attention-Related Cognitive Errors Scale (ARCES) and we also examined the actual occurrence of action slips with the Slip Induction Task (SIT) and the Sustained Attention to Response Task (SART). Our results suggest that contrary to the 'senior moments' assumption, older adults actually commit the same or fewer attention errors on both the SIT and the SART and they also report fewer attention failures in everyday life compared to what has been shown in the literature for younger adults. However at least for the SART and SIT, this increased accuracy appears to come at a cost of task speed. As such, it is probable that older adults invoke a series of strategies including a shift toward valuing accuracy over speed to maintain attentive performance in lab based tasks and perhaps in daily life as well.

INTRODUCTION

Regardless of age, everyone experiences slips of action in one way or another. Often times these errors are simply an annoyance – a speed bump of sorts while we are trying to go about our everyday life. Perhaps it's driving by the grocery store on the way home from work even though you really needed milk… or maybe its failing to add sugar to your daily cup of coffee because you were interrupted by a phone call. These seemingly harmless everyday attention errors can manifest themselves in very dangerous ways however, resulting in accidents or injuries. As such, understanding the conditions under which slips of action are likely to occur as well as precautions that can be taken to prevent such errors is desirable.

Robertson and colleagues (1997) have suggested that action slips are due to consciousness becoming absent or at least disengaged from the task at hand which may be a result of the task becoming overly practiced (Reason & Mycielska, 1982). Since these conditions require very few attention resources we become prone to distraction, boredom, and at times, slips of action (Broadbent, Cooper, FitzGerald & Parkes, 1982). Further, Norman and Shallice's model of action (2000) suggests that whenever little conscious attention is required for a task, a contention scheduling system (CS) is allowed to operate and this system functions much like 'auto-pilot' in that task demands are assumed to remain stable and actions to achieve task goals are performed almost automatically. While this system is economical in terms of resources, an unfortunate side effect is that when the demands or goals of the task are altered in some way they rarely translate into changes in actual task execution. Instead, errors, or action slips, often occur.

Errors of this sort are sometimes colloquially referred to as ‘senior moments’ and they presumably get this name because it is assumed that their occurrence increases with and becomes exacerbated by age. Indeed, Layton (1975) has suggested that older adults are more affected by both distracters in the environment and within their own selves and this heightened sensitivity to distractions may be the result of an observed age-related decline in one’s ability to suppress, or inhibit, unimportant information when completing tasks requiring selective attention and working memory (Tipper, 1985; Hasher, Stoltzfus, Zacks & Rypma, 1991).

Conversely however, others have indicated that older adults are generally more engaged in goal-directed tasks and there tends to be a negative correlation between age and self-reported task-unrelated thoughts (daydreaming/mind wandering about things extraneous to the task at hand) during both vigilance tasks (Giambra, 1989) and simple prospective memory tasks (Einstein & Mcdaniel, 1997). In addition, though Jonsdottir, Adolfsdottir, Cortez, Gunnarsdottir and Gustafsdottir (2007) did not know what to make of their findings, they did observe a negative correlation between age and action slips as measured by a diary study similar to what Reason employed (1979). If it is true that older adults are less prone to task-unrelated mind-wandering, it follows that slips of action should in fact be less frequent with age, particularly if they are indeed the result of disengaged conscious attention. Furthermore, if slips are indeed the price of automatization, where Norman and Shallice’s (1986) CS fails to appropriately allocate attention to noticing new, unexpected information about a routine task, it is possible that the observed decline in older adults’ ability to suppress extraneous information (Tipper, 1985; Hasher et al, 1991) may actually work in their favor – potentially protecting them from missing important information that might lead to an action slip.

Corroborating evidence for a hypothesis of decreased attention failures in older adults comes from literature on speed-accuracy trade offs in older versus younger adult samples. Salthouse (1979) has found that older adults typically favor increased accuracy over speed in self-paced tasks while younger adult participants tend to prefer to finish tasks quickly despite sacrificing some accuracy for that goal. With respect to action slips, these findings suggest that older adults would likely prefer to execute routine tasks more slowly in an effort to avoid slips of action.

This study was designed to examine the validity of the widely held assumption that older adults make more errors while executing routine, everyday tasks. To accomplish this, we looked specifically at the occurrence of slips of action in the Slip Induction Task (SIT) as well as failures of sustained attention and inhibition in the Sustained Attention to Response Task (SART, Roberston et al, 2997). Finally, we also collected subjective reports of everyday attention failures with the Attention-Related Cognitive Errors Scale (ARCES; Cheyne, Carriere & Smilek, 2006) which asks participants to rate how often they experience certain attention related errors like, "I make mistakes because I am thinking about one thing and doing another" on a scale of one (never) to five (very often).

The SIT (Clark, Parakh, Smilek & Roy, in preparation) attempts to mimic an everyday action routine within a controlled laboratory setting. As such, participants learn a series of hand movements to target buttons as instructed by arrow cues and they practice this series of movements hundreds of times until it becomes highly practiced;

similar to a simple morning routine of making one's cup of coffee. After this period of learning, participants continue to execute the practiced sequence of hand movements, but occasionally, the task demands change in that one of the arrow cues within the sequence is altered. This alteration to the expected movement sequence involved either a change in the spatial location of the arrow cue such that the cue would no longer be congruent spatially with the target button (positional alteration), the pointed direction of the arrow cue such that the cue would be located in the expected spatial location but pointed to an unexpected target button (directional alteration), or a combination of the above (combined alteration).

Previous experiments using the SIT have found that young adults make frequent errors when confronted with unexpected cue information. Specifically, while all three types of manipulations to the expected arrow cues resulted in significant declines in accuracy, Clark, Parakh, Smilek and Roy (in preparation) found that performance was least affected by positional alterations in which the spatial location of the arrow changes but the movement goal remains as expected. Furthermore, participants' accuracy was most affected by directional alterations, where the exogenous, spatial location of the arrow cue remains as expected but the arrow points toward a new target location which required participants to interrupt their automatic response and instead adopt a new movement goal.

In this study, we expected that older adults would also commit numerous slips of action when confronted with unexpected arrow cue information and that they, like the young adults, would find the directional alterations most detrimental and the positional alterations least harmful to performance. What was unclear however was whether the ‘senior moments’ assumption would be supported and older adults would be more prone to action slips than has been reported for younger adults by Clark, Parakh, Smilek and Roy (in preparation). The more likely hypothesis however is that older adults will commit fewer errors when they encountered unexpected arrow cue information, either because they do not suppress the arrow cues like younger adults do (Tipper, 1985) or because they move at a slow enough pace that they are able to successfully inhibit their ‘automatized’ action routines. If this speed accuracy relationship is true, we also expect that the beneficial effect of a generally slow pace of task on accuracy would not be unique to the SIT but will also enhance SART performance and attention related cognitive errors in everyday life as measured by the ARCES.

METHOD

Participants and Procedure.

Twenty-four, right-handed, healthy older adults (average age of 68 years at time of testing) were recruited from the Waterloo Research in Aging Pool to participate in this study where slips of action were induced by requiring participants to deviate from a well-learned movement sequence. Upon arrival at the laboratory, participants were informed of the general procedures of the study and the risks and benefits that they might incur. After giving their informed consent, participants completed the SART, which required participants to withhold their response to an infrequent target, and the ARCES and then proceeded directly to SIT.

As has been discussed in the general introduction of this paper, directional arrow cues for the movements within the sequence were delivered on a computer screen and projected onto a mirror that was directly above a response board. The arrow cues measured 70 mm in length (creating a visual angle of between 11° and 16°), and 50 mm in height (creating a visual angle of between 9° and 13°) and were displayed 125 mm from the center of the screen in one of four directions. The response board contained five response buttons; one above, below, to the right and to the left of a central home button. Participants were instructed to always move to, and press, the target button which corresponded with the pointed direction of the arrow cues. Each sequence of movements began with the appearance of a fixation cross in the center of the screen. After a variable period, the fixation cross disappeared and through a series of button presses and releases measures of initiation to move to arrow cues (IT), movement time to target buttons (MT), return to home time for movements back to the home button to receive the next cue (RTH) as well as overall time to complete an entire sequence of seven movements (ST) was recorded.

The SIT is organized into two separate phases, the initial learning phase and the alteration phase. During the training phase, participants were randomly assigned to practice the sequence of seven hand movements for either one block of 120 trials or three blocks of 120 trials. Regardless of the amount of practice however, the participants received the same instructions and the learning phase always began by quickly getting acquainted with the button locations on the response board. Once familiar with the response board, participants were informed that a series of arrows were going to appear and their task was to move as quickly and as accurately as possible to the buttons on the response board that correspond with those arrows. During this training session, the position and direction of the arrow cues were never manipulated and the participants were informed that this was the case.

Five to eight days after the training phase, each participant returned to the laboratory for the experimental session. In this second session of the study, each participant was required to complete 5 blocks of experimental trials with 120 trials per block. Out of these 600 sequences, 24% of the trials contained an altered movement where any one of the movements within the sequence could have been altered in one of three ways. Forty-two of the trials contained a positional alteration (see full description in Chapter One, Figure 1.1, p.19), where the cue was located in an unexpected spatial position only. Seventy of the trials contained a directional alteration (see full description in Chapter One, Figure 1.2, p.20), where the cue remained in the expected spatial position but pointed in an unexpected direction. Another twenty-eight involved the combined alteration (see full description in Chapter One, Figure 1.3, p.21), where both the spatial position and pointed direction of the cue was unexpected.

At the beginning of this experimental phase of the study, participants were informed that a portion of the sequences would be changed in some way and that their task would be to follow the arrow's instructions. As such, if an arrow appeared that pointed to a new target, they were to move to that new target as quickly and as accurately as possible. Before actually commencing the phase of the study where some trials would be altered, the participants were first given an opportunity to become reacquainted with the movement sequence on a series of 60 reminder trials that were not altered in any way. For the first few minutes of both the learning and alteration phases an experimenter stayed with the participant to ensure that they had understood the instructions and participants had an opportunity to ask questions while actually experiencing the protocol.

Analyses.

Exclusion Criteria for Slip Induction Task.

If ST or MT data points fell outside a predetermined range which was based on both logic (i.e., a movement to a target less than 15 cm away should not require more than five seconds) and normal distribution for that measure (i.e., any amount of time that was more than two standard deviations away from the mean) that individual data point was excluded from analyses. The allowable range for any individual ST was between 2000 and 15000 ms and only 1% of trials were excluded based on an ST occurring outside this range. The allowable range for MT data was between 40 and 5000 ms and less than 1% of MT data points were excluded because of this criterion. Exclusions based on IT were also possible and the allowable range for this measure was between 40 and 5000 ms. This criterion presumes that ITs less than 40 ms probably did not reflect an actual response to a cue, but instead were most likely a measures of anticipation to move to an expected location. However, these situations were quite rare and only 3% of IT data points were excluded from analyses. While it was also possible for an IT data point to be excluded because it was too slow, no data points were excluded because of this.

In addition to having individual data points excluded, data for trials that contained a combined alteration was missing for two separate participants. This was the case because these two participants were unable to complete the last two blocks of trials in the alteration phase. As such, no trials with a combined alteration were completed by these participants.

Finally, one additional participant was excluded from all data analyses. This participant's data was excluded because regardless of whether a trial was altered or not, or what type of alteration was encountered, his average ST was always more than two standard deviations longer than the mean for the group and his average MT was often outside the normal range as well. Even though a total of 16% of his ST data points were excluded from his average ST because they were outside the allowable range, his average ST was still significantly outside the normal range for the group. Finally, while his accuracy data did not fall outside the normal range for the group, it was also excluded since longer average STs and MTs were likely to have impacted this measure as well.

Accuracy: The effect of alterations and practice amount.

The first point of interest in this study was to determine whether the alterations were successful at causing slips of action within an older adult sample, and if so, whether any one of the alteration types was more likely to induce slips than the others. To accomplish this, accuracy was computed by first tallying the number of times in which a participant pressed a button that was not indicated by the arrow cue. These errors were then grouped according to whether the slip was on a directionally altered trial, a positionally altered trial, a trial with a combined alteration, or a trial that was not altered in any way. These four error frequencies were converted into percentage accuracy scores by dividing the error frequency by the total number of trials in which that type of error was possible.

In addition to simply considering which alteration types impacted accuracy, we were also interested in learning whether more experience with the movement sequence during the learning phase would impact participants' subsequent accuracy during the alteration phase. As such, an omnibus mixed model ANOVA was conducted in which the percentage accuracies for the four types of possible errors (unaltered, positional, directional and combined) were included as within-subjects factors and amount of practice during the learning phase (120 trials or 360 trials) was included as a between-subjects factor. Three planned contrasts were integrated in this analysis such that accuracy on trials that were not altered was compared to accuracy on positionally altered trials, directionally altered trials, and trials that contained a combined alteration. In addition, three additional t-tests (with corresponding Bonferoni α-level corrections) were required to directly compare accuracy between positionally altered trials, directionally altered trials and trials with a combined alteration.

Timing: The micro-structure.

The design of the SIT also allows for a more careful consideration of the impact of alterations on participants' behavior. Measures of ST, IT and MT afford the opportunity to consider the potential reciprocal effect(s) of speed on accuracy when altered sequences are encountered. Consequently, a series of one-way ANOVAs, and corresponding Tukey's b post hoc tests, were used to compare participants' average STs, ITs and MTs on actual altered trials in which an error was made, altered trials that the participant completed correctly and trials that were not altered.

Timing: Pace and likelihood of slips.

We predicted that the general pace at which participants completed the SIT would relate to how accurately they reconciled unexpected arrow cue information. As a result, a series of Pearson correlations were conducted to determine if a relationship existed between number of errors overall on altered trials, accuracy on the three separate types of altered trials, unaltered ST and altered ST. In addition, using a step-wise multiple regression unaltered ST, altered ST and practice amount were tested for their ability to explain variance in participants' errors on altered trials

Considering congruence with other measures.

To determine the extent to which other measures of inattention predict performance on the SIT, a number of Pearson correlation analyses were completed. Firstly, the SART task features measures of misses (situations where a button press is not withheld when it should have been), false alarms (situations where a button press is withheld inappropriately) and response times to both regular trials (RT) and trials in which a response is to be withheld (ErrorRT). In addition, participants' subjective reports of experiencing attention failures in daily life were scored on the ARCES questionnaire. Using a series of Pearson correlations, SART misses, SART false alarms, SART RT, SART ErrorRT and ARCES scores were correlated with the total number of errors, the number of errors made on altered trials and the number of errors made on unaltered trials on the slip induction task. Finally, to ensure that these results were interpretable in light of the literature available on these two measures, correlations were also conducted to investigate the degree to which ARCES scores predicted performance on the SART.

RESULTS

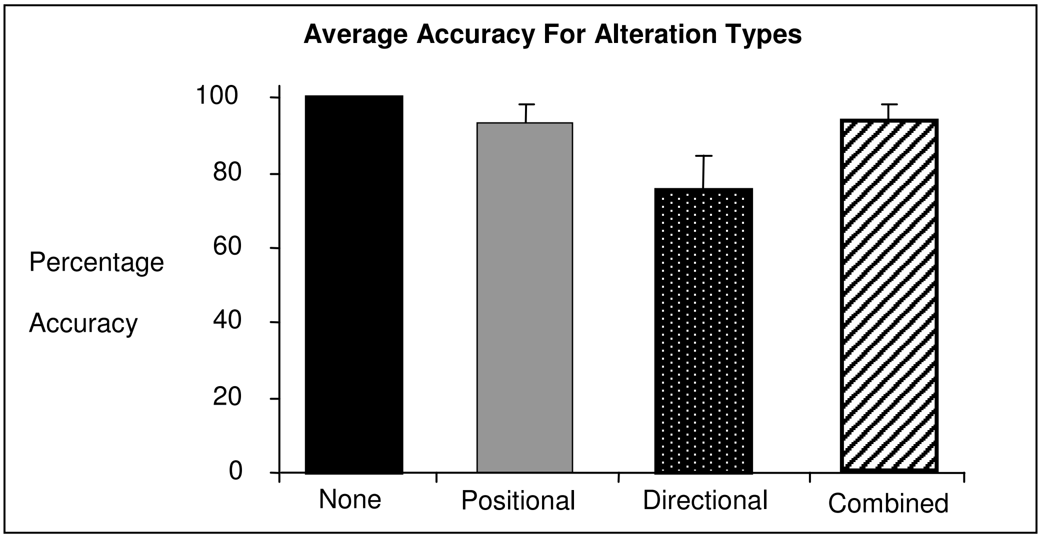
As predicted, we found a significant main effect of cue alteration on accuracy ($F(3,20)=40.61$, $p<0.001$). In addition, planned comparisons revealed that accuracy for positional alterations ($F(1,19) = 24.368$, $p<0.001$), directional alterations ($F(1,19) = 86.863$, $p<0.001$) and combined alterations ($F(1,19) = 21.996$, $p<0.001$) each significantly differed from trials in which no alteration from the expected sequence occurred.

Mean accuracies and variability information for each alteration type can be seen in Table 3.1 and Figure 3.1. These data reveal that as hypothesized, the older adults in our study followed a similar accuracy pattern as has been reported in younger adults (Clark, Parakh, Smilek & Roy, in preparation) in that their accuracy was worse on directionally altered trials than on trials that contained a combined alteration ($t(20) = 6.551$, $p<0.001$) or positionally altered trials ($t(20) = 6.454$, $p<0.001$). In addition, though positional alterations did lead to more errors than trials that were not altered in any way, even so they were least detrimental to accuracy on the task.

Table 3.1: Descriptive Statistics for Accuracy Data during Alteration Phase

	Unaltered Accuracy		Positional Accuracy		Directional Accuracy		Combined Accuracy		Total Errors: Altered Trials	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
120 Trials	99.71	0.24	93.07	5.05	74.67	15.03	87.66	14.39	22.23	10.27
360 Trials	99.84	0.19	93.33	7.25	69.42	11.98	87.87	8.12	27.36	9.44

Figure 3.1: Accuracy Data During Alteration Phase



Participants in this study were less affected by the combined alterations than has been found in other young adult samples. In fact, after taking into consideration a Bonferoni α-level correction for multiple comparisons, making the critical p-value 0.0125, their accuracy for combined alterations did not significantly differ from accuracy for positional alterations (t (20) = 2.093, p=0.049).

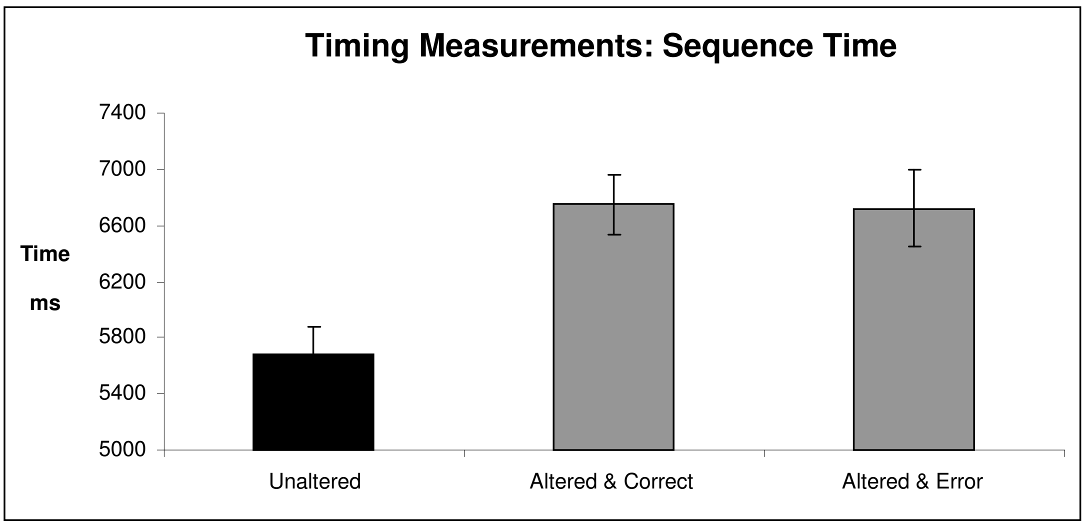
Furthermore, evidence was not found for an impact of practice during the learning phase on accuracy on trials with unexpected cue information during the alteration phase as neither a main effect of practice (F(1,19) = 0.195, p=0.664), nor an interaction of practice and alteration type was found (F(3,57) = 0.539, p=0.663).

When considering the timing measures, a main effect of ST was found (F (2,40) = 80.252, p<0.001) such that any sequence that contained an alteration required more time to complete than those sequences that were unaltered, see Table 3.2 and Figure 3.2.

Table 3.2: Descriptive Statistics for Timing Data during Alteration Phase

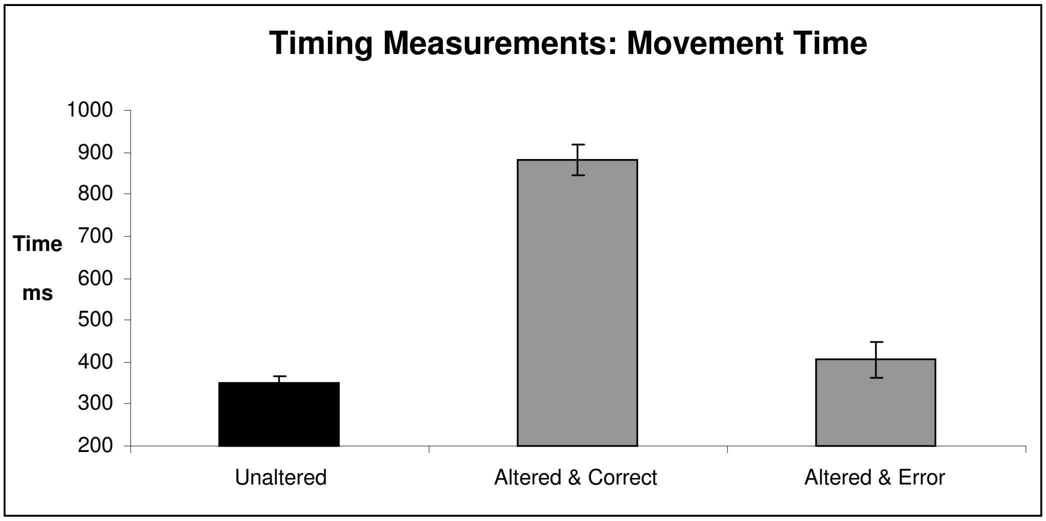
	ST (in ms)		MT (in ms)		IT (in ms)	
	Mean	SD	Mean	SD	Mean	SD
Unaltered Trials	5682.33	896.09	349.42	78.37	172.13	33.41
Altered & Error Trials	6791.07	1256.13	405.49	199.22	155.58	39.56
Altered & Correct Trials	6750.16	981.61	882.35	166.60	171.73	37.04

Figure 3.2: STs for Unaltered, Altered & Correct and Altered & Error Trials



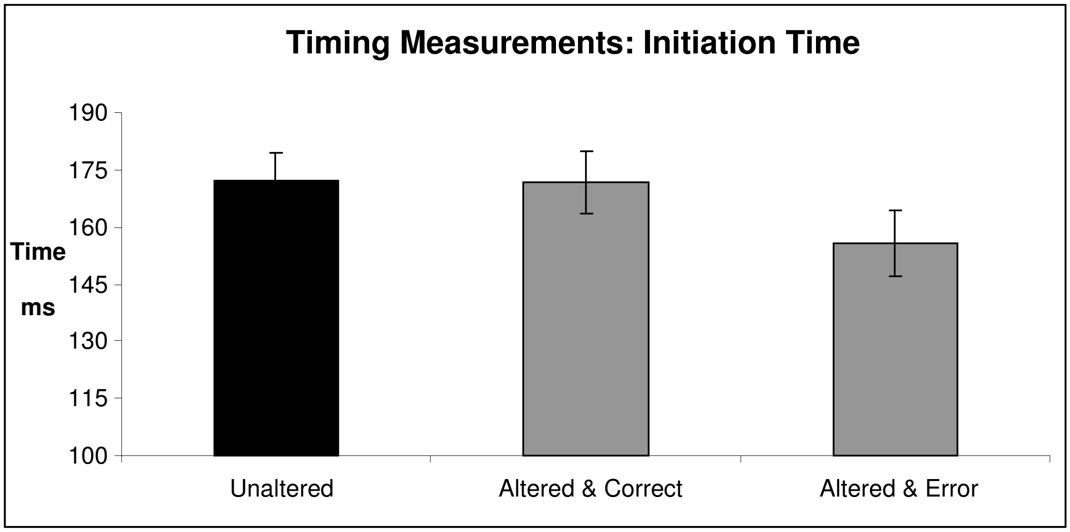
Another main effect was found with respect to MT (F(2,40) = 164.93, p<0.001), see Figure 3.3, such that on trials in which an alteration was present and the participant was able to respond correctly to the unexpected cue information, participants had significantly longer MTs (x = 882.35, SD = 166.60) than for trials where an error was made on the altered trial (x = 405.49, SD = 199.22; t(20) = 4.185, p<0.001) or no alteration occurred (x = 349.42, SD = 78.37; F(1,20) = 24.69, p<0.001).

Figure 3.3: MTs for Unaltered, Altered & Correct and Altered & Error Trials



Interestingly though, when considering the IT measure, while yet another main effect is found ($F(2,40) = 13.264$, $p<0.001$; see Figure 3.4), planned contrasts and post-hoc tests reveal that the effect is quite different from what was seen for MT. Instead, of observing an increase in MT on trials that were altered but executed correctly compared to when an error was made or the trial was not altered, we find that participants initiated their movement significantly faster on altered trials in which an error would be made (x = 155.58, SD = 39.56) than when that trial would be completed correctly (x = 171.73, SD = 37.04l; $t(20) = 4.185$, $p<0.001$) or the trial was not altered in any way (x = 172.13, SD = 33.41; $F(1,20) = 14.685$, $p<0.001$).

Figure 3.4: ITs for Unaltered, Altered & Correct and Altered & Error Trials



Speed of Task and Propensity for Errors

To better understand the mechanisms that allowed for the considerably high accuracy rates that we observed in this study of older adults, we explored how accuracy might relate to the amount of time that participants took to complete the sequences within the SIT. Since the ST measure takes ITs and MTs for all trials within a sequence into consideration, we used average times to complete an unaltered sequence as well as average times to complete a sequence in which one of the three alterations was present to predict errors on altered trials.

Pearson correlations for each of the relationships described above can be found in Table 3.3. These analyses indicate that speed of task, as measured by both ST of regular, unaltered trials as well as ST of altered trials and MT of both unaltered and altered trials correlates negatively with frequency of errors on altered moves. This relationship is examined with slightly more precision by considering how speed relates to the likelihood of committing a slip of action on positionally, directionally and combined altered trials individually. Here we find that ST, be it for unaltered or altered trials, correlates only with accuracy on trials that contained a directional alteration. This suggests that participants who executed the task more slowly (longer sequence times) were more likely to adjust their movement plan to coincide with arrows that were spatially located where expected but pointed to an unexpected target button.

Table 3.3: Correlations between Speed of Task and Errors/Accuracy

	Unaltered ST	Unaltered MT	Altered ST	Altered MT
Altered Errors	**r = -0.665, p=0.001**	**r = -0.545, p=0.009**	**r = -0.608, p=0.003**	**r = -0.509, p=0.018**
Positional Accuracy	r = -0.05, p=0.827	r = -0.123, p=0.585	r = -0.104, p=0.180	r = -0.168, p=0.455
Directional Accuracy	**r = 0.668, p<0.001**	**r = 0.548, p=0.008**	**r = 0.525, p=0.012**	**r = 0.463, p=0.030**
Combined Accuracy	r = 0.405, p=0.068	r = 0.292, p=0.199	r = 0.319, p=0.159	r = 0.265, p=0.246

Given the correlations between speed of task and errors, a multiple regression was conducted to determine the degree to which altered ST, unaltered ST and practice amount during the learning phase uniquely contribute to the prediction of action slips (Table 3.4 and Table 3.5). Even when practice amount was entered into the model first, it did not significantly predict participants' likelihood of making an error. However, unaltered and altered STs shared enough variance with each other that one was not a significant predictor after entering the other into the model first. However, the R squared value was higher when unaltered ST was entered into the model before altered ST instead of after.

Therefore, while altered ST was only significant when entered before unaltered ST and vice versa it appears that unaltered ST is the best predictor of number of errors made in the SIT.

Table 3.4: Model One Regression Data for Explaining Variance in the Number of Errors made on Altered Trials in the SIT.

Model One			
	R value	R squared	R squared change
Step 1: Practice Amount	0.303	0.092	0.092, p=0.182
Step 2: Altered ST	**0.614**	**0.377**	**0.286, p=0.01**
Step 3: Unaltered ST	0.669	0.447	0.070, p=0.161

Table 3.5: Model Two Regression Data for Explaining Variance in the Number of Errors made on Altered Trials in the SIT.

Model Two			
	R value	R squared	R squared change
Step 1: Practice Amount	0.303	0.092	0.092, p=0.182
Step 2: Unaltered ST	**0.666**	**0.444**	**0.353, p=0.003**
Step 3: Altered ST	0.669	0.447	0.003, p=0.770

Out of a possible score of five, which would indicate a high occurrence of attention failures in daily life (ARCES), the older adults in our sample had an average score of 2.41 with a standard deviation of 0.39. While this measure of attention failure in daily life did not significantly correlate with actual propensity to make action slips on the SIT or the SART within this small sample (see Table 3.7), we did find that higher scores on the ARCES correlated negatively with MT on altered trials (r = -0.433, p=0.04) and this relationship trended toward significance with ST of altered trials (r = -0.401, p=0.06). With respect to the SART, older adult participants made an average of 12.5 (SD=6.29) commission errors (where a response to the target is not withheld) and erroneously responded to those targets in an average of 347.25 ms (SD = 62.45). In addition, on regular trials, where participants were supposed to respond, they had an average response time of 352.91 ms (SD = 50.51). The observed relationship between attention related failures in daily life (ARCES) and performance speed on the SIT was also observed when considering response time to regular trials on the SART (r = -0.485, p=0.02). Moreover, while faster response times on the SART were correlated with increased SART commission errors (r = -0.614, p=0.002), despite speed correlations (see Table 3.6) between the tasks, commission errors nor response times on the SART predicted performance on the SIT (see Table 3.7).

Table 3.6: Correlations between Response Times on the SART and Speed of Task on Slip Induction Task

	SART Response Time
Unaltered Sequence Time	**r = 0.505, p=0.017**
Unaltered Movement Time	**r = 0.531, p=0.013**
Altered Sequence Time	**r = 0.602, p=0.004**
Altered Movement Time	**r = 0.483, p=0.023**

Table 3.7: Correlations between the SIT and Other Measures of Inattention

	ARCES	SART Errors
Altered Errors	r = 0.129, p=0.568	r = -0.055, p=0.812
Unaltered Errors	r = 0.001, p=0.996	r = -0.307, p=0.164
Positional Accuracy	r = 0.152, p=0.501	**r = 0.488, p=0.03**
Directional Accuracy	r = -0.148, p=0.511	r = -0.318, p=0.160
Combined Accuracy	r = -0.204, p=0.375	r = -0.122, p=0.608
ARCES		r = 0.130, p=0.564

DISCUSSION

Previous studies using the SIT have shown that action slips are possible to induce in young adults within a laboratory based task (Clark, Parakh, Smilek & Roy, in preparation, Clark & Roy, in preparation). In this task, participants executed a well-learned action routine several hundred times and occasionally encountered unexpected arrow cue information. This unexpected cue information consisted of a manipulation of the physical location of the cue and/or the pointed direction of the arrow. Participants were told that at times these infrequent changes to the routine would occur and that their goal would be to adjust their expected movements when appropriate given the pointed direction of the arrow cues. Critically, since the routine was well-learned for the participants, active attention to the cues was not always important and as such, participants often failed to adjust their expected movement plans when unexpected arrow cue information was encountered. In fact, for unexpected cues that were located in the expected physical location, but pointed somewhere new (directional alteration), participants only changed their expected movement to coincide with the new cue 30% of the time.

The main purpose of this study was to determine if the SIT could also be used to induce attention related errors during the execution of a routine task in older adults. As such, participants between the ages of 60 and 80 years of age completed the SIT in much the same way as the younger adults in Clark, Parakh, Smilek and Roy (in preparation) did. In addition to determining how accurately participants would respond to unexpected cue information, we also measured the speed at which they completed each repetition of the sequence (ST) as well as their individual times spent initiating a movement to the cues (IT) and moving to the actual target buttons (MT). These timing measures were used to examine how alterations to the expected sequence affected speed, both overall and in the micro-structure of a sequence, and how speed of task correlated with accurate performance.

Anecdotal accounts would suggest that attention-related errors in everyday life are a common occurrence in old age. In fact, terms like "senior moments" have become part of the lexicon we use to describe the memory and attention complaints that supposedly come along with healthy aging. Interestingly though, while the results of our study using the SIT with an aging sample reveal that older adults certainly make several errors when they encounter infrequent changes to a routine movement sequence, they actually make fewer slips on trials that contained directional or combined alterations than has been reported in younger adult samples (25% accurate for directional alterations, 36% accurate for combined alterations; Clark, Parakh, Smilek & Roy, in preparation; 23% accurate for directional alterations, 58% accurate for combined alterations; Clark & Roy, in preparation). Indeed, upon directly comparing the data for the older adults from this chapter to the young adults from Chapter Two using a four (alteration type) by two (age group) mixed ANOVA with age group as the between subjects factor, a main effect of age is found such that older adults are significantly more accurate than the younger adults ($F(1,46) = 77.689$, $p<0.001$). Additionally, a two-way interaction between age group and alteration type is found ($F(3,138) = 70.618$, $p<0.001$) and post-hoc analyses reveal that older adults were only more accurate on trials that contained a directional or combined alteration. Moreover, as is evident in Table 3.8, average accuracy on directionally altered trials for this sample of older adults was well outside the one-tailed 95% confidence interval that is established for the young adult study discussed in Chapter Two.

Table 3.8: Comparing Older Adult SIT Accuracy to Younger Adult Samples

	Average Accuracies from Current Study	Percentage of Older Adult Participants whose Mean Accuracy Falls Outside of CI	Upper Limit of Accuracy CI (Clark & Roy, in preparation)
Directional Alteration	72.17	91%	48.35
Combined Alteration	87.76	27%	94.35

Despite being much more accurate on directionally altered trials, both young and old participants were most challenged by situations where the physical location of the cue remained as is expected, but the pointed direction of the arrow was inconsistent with what would be expected at that point in the sequence. Unlike young adults however, older adult participants had very little difficulty correctly completing sequences that contained a combined alteration. In fact, they were able to handle these altered trials just as well as those with a positional alteration where no change in movement goal was required.

This difference between participants in the current study and reported accuracies for younger adults (Clark, Parakh, Smilek & Roy, in preparation, Clark & Roy, in preparation) is quite compelling and provides definite insight into how attentional control of routine tasks may change with age. A critical feature of a combined alteration in the SIT is that the altered cue visually appears in an unexpected physical location. Since older adults seem particularly able to handle alterations of this sort, it suggests that the unexpected exogenous information that occurs with a combined alteration must be especially salient for older adults. In fact, it must be salient enough to capture attention away from the well-rehearsed movement routine which is controlled by the CS. This capture likely allows the opportunity for participants to consider the endogenous information contained in the cue, thus requiring a switch to the SAS. As such, the older adults have the opportunity to determine if they should move to the expected target, which would be the case for a positional alteration, or to a new, unexpected target, a combined alteration. Given that participants in this study were equally accurate on trials that contained a positional or combined alteration, making errors on only about 10% of trials, it does appear that older adults are particularly able to use unexpected exogenous cue information to facilitate the switch from the CS to the SAS.

Taken together, the accuracy results from this study provide a potential explanation for some of the inconsistencies that are found in the literature regarding limited inhibition/suppression of information with increasing age. Much debate has surrounded Hasher, Stoltzfus, Zacks and Rypma's (1991) assertion that older adults are unable to inhibit both internal and external distracting information and this inability leads to declines in memory and attention performance. Partial disagreement with their theory stems from a growing body of evidence led by Giambra (1989) that older adults actually engage in less mind-wandering (an internal distraction) than their young adult counterparts.

Results from the SIT indicate that these theories may not be mutually exclusive. In order to avoid an action slip when unexpected cue information is encountered, attention must be allocated to the cue itself. If that cue is considered irrelevant, the cue may be suppressed and an error is likely to occur. Importantly, while suppression is apt to benefit performance in selective attention tasks, in the SIT, suppression of arrow cues is actually likely to induce a slip. Older adults in the current study made significantly fewer slips than younger adults (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation) and this is especially true for accuracy on trials with a combined alteration. This difference in performance mirrors Hasher and colleagues' theory of decreased suppression abilities with increased age, but instead of impeding performance, the older adults' inability to suppress actually enhanced their accuracy. On the other hand though, it is clear that older adults did suppress some cue information since they still made many errors, especially on directionally altered trials. Given their selective difficulty with directional alterations, it is probable that an ability to suppress endogenous information is, at least partially, retained with advanced age.

Additionally, Giambra's (1989) finding that older adults engage in less task-unrelated thoughts (internal distractions) than younger adults is also supported by the increased accuracy that is enjoyed by older adults on the SIT. Furthermore, the observed relationship between SIT performance and ARCES scores suggests that a decreased propensity to attention related errors in everyday life is predicted by one's accuracy on the SIT and both of these findings might be linked to a decreased probability of engaging in task-unrelated thought.

Findings related to the timing of the movements during the SIT provide additional information about how the participants in the current study may have been able to perform the task with so much more accuracy than what has been found in younger adult samples (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation). These data point toward a speed accuracy trade off as would be predicted by Salthouse (1979) but it speaks specifically to accuracy on directionally altered trials, where both age groups appear to have failed to allocate appropriate attention to the endogenous information in the unexpected arrow cues. Correlation results from the current study with older adults reflect a strong relationship between general pace of task (as measured by ST of unaltered trials) and a participants' likelihood of making an error on an altered trial. Therefore, participants who executed the task more slowly overall were better equipped to change their expected movement plan to coincide with the new pointed direction of the cue. Also, a multiple regression analysis provided corroborating evidence in that variance in number of errors committed on altered trials was best predicted by participants' ST of unaltered sequences.

Importantly though, this observed relationship between pace and error was also reported in a young adult sample (Clark & Roy, in preparation). Where the young adult study and the current study differ however is in how well general pace of task predicts accuracy for each of the three types of alterations. Clark and Roy (in preparation) report that accuracy for all three types of alterations is negatively correlated with general pace of task (as measured by ST of unaltered trials), for older adults however, only accuracy on directionally altered trials is predicted by general pace. This difference between the studies may suggest that whenever a participant is completing a task quickly and suppressing cue information, that participant's likelihood of being able to adjust their movements to coincide with a change in the arrow cues, is low. However, when that participant is moving at a generally slower pace and not suppressing the arrow cues (either because they prefer not to or because they are unable), that participant's ability to avoid an action slip is significantly reduced. Given our results, it is clear that a lack of suppression, slower pace and an increased likelihood to switch to the SAS when necessary all coexist in an effort to avoid errors during a routine task. What remains unclear however is what, if any, of these factors is the cause of increased accuracy on the SIT. Several possible explanations exist including that participants' slower speed is a result of the increased processing demands of not inhibiting competing information; that a purposeful slower speed allows a greater opportunity for the SAS to interrupt the CS when necessary; or additionally that older adults, who are slower overall than young adults, choose to employ the CS less often for routine action to avoid errors and this has a side-effect of slower responding. Additional studies must be designed to carefully control and/or manipulate these factors to determine the degree to which they interact and potentially cause increased accuracy on the SIT.

Finally, like Clark and Roy (in preparation) report for young adults, the timing of specific movements for participants in the current study was significantly impacted by the occurrence of alterations to the routine movement sequence. Whenever an alteration was encountered on one of the movements within the seven movement sequence, the time required to complete that sequence (altered ST) was significantly longer than for sequences where no alteration occurred. Because the average time required for an entire sequence could be affected by several factors other than the actual altered movement, we looked more closely at the microstructure of the sequence to determine the impact of alterations on IT and MT of the actual altered movement. Our results indicate that participants' IT and MT were impacted uniquely depending on whether an alteration resulted in an error or a correct response. Specifically, while participants tended to initiate movements on altered trials that would eventually be completed correctly in the same amount of time as trials that were not altered in any way, being able to complete the movement correctly was accompanied by a dramatic cost in the online time required to move to the appropriate target button. Conversely, when a participant was about to make an error on an altered movement they happened to initiate that movement more quickly than usual to the arrow cue and also moved to the target at a similar speed to what was average for unaltered movements, almost as if they failed to recognize in time that the movement had to be altered at all. This pattern of results was also reported by Clark and Roy (in preparation) for their young adult sample but it is unclear whether the older adults' STs, ITs and/or MTs were more or less affected by the alterations to arrow cues. As such, a further experiment which was designed to directly compare younger and older adults on these timing measures as well as accuracy overall would be a beneficial complement to this paper.

CHAPTER FOUR: Preventing Slips of Action by Slowing Task Pace

OVERVIEW

Errors of attention during the execution of routine or tedious tasks, also referred to as slips of action, have been successfully created within a laboratory environment with the Slip Induction Task (SIT). With this task, errors are induced by occasionally requiring participants to deviate from a well-learned movement sequence by including intermittent, unexpected arrow cue information. These unexpected arrow cues can act as a simple distracter (when the cue's location is unexpected) and/or can require participants to adjust their expected movement goals by pointing toward a different target button than usual. Clark, Parakh, Smilek and Roy (in preparation) have reported that young adults have particular difficulty with this task when the unexpected cue information requires a change in movement goal. In a later study with older adults however, Clark, Rose and Roy (in preparation) found that while they still make frequent errors, older adults are significantly more accurate and appear to sacrifice task speed for fewer slip commissions. To determine if young adults can use this strategy to improve their performance on the SIT, this study encouraged twenty-seven healthy, young adult participants to complete each movement sequence within a similar amount of time as has been observed in older adults (Clark, Rose & Roy, in preparation). Our results indicate that participants were able to successfully use timing feedback to ensure that they executed most sequences within the desired time range. In addition, compared to what has been reported by Clark, Parakh, Smilek and Roy (in preparation) the participants in the current study completed sequences more slowly and more accurately when changes in movement goal were required.

INTRODUCTION

Failing to check one's blind spot when changing lanes or not noticing a new stop light at an intersection on one's way home from work are dangerous yet common mistakes made by many experienced drivers. While it is easy to appreciate the costs that could arise as a result of these mistakes it is also important to recognize the costs associated with some of the less dangerous but still annoying everyday errors that we all make. Meaning to turn left at an intersection to pick up some milk but instead turning right toward home like every other day is a common example of an annoying everyday error, or action slip, that results in lost time and efficiency and unnecessary frustration.

Even in the late 1800's William James (1890) wrote, "…habit diminishes the conscious attention with which our acts are performed…" and based on James' work several of his contemporaries strove to determine how and why errors in everyday routine actions occur. Reason and Mycielska (1982) suggest that "these mistakes are the price we pay for being able to carry out so many complex activities with only a small investment of conscious attention" (Reason & Mycielska, 1982, pp. 243). Consequently, Norman and Shallice (1986) and Shallice and Burgess (1993) propose a model of action in which they suggest the existence of two systems of attention control, one, the supervisory attention system (SAS), operates under direct conscious attention, where tasks are monitored closely to avoid error during the execution of novel or very important tasks. The other, the contention scheduling (CS) system, operates like an 'auto-pilot' for the execution of well-practiced, routine actions that typically require little to no conscious attention control. According to Norman and Shallice (2000) these systems have independent neural bases and typically operate independently of each other, but at critical moments, the SAS will need to interrupt the CS' usual routine to accommodate new task goals or demands. Importantly though, the effectiveness of this intervention appears to be reliant on having sufficient sustained attention to the task, and perhaps time to allow for the CS to SAS switch, at those critical moments.

Similarly, diary studies conducted by Reason (1977, 1979, 1984) led to the adoption of a concept known as critical decision points, which Reason describes as junctures in time where participants needed to ask themselves about the goals of their task(s) and what actions had been done up to that point to achieve those goals (Reason, 1979). For example, if one is making a sandwich, one must consider whether they would like mustard, and if so, whether or not mustard has already been added to the sandwich. If one does not consider those questions, they are at risk of failing to add a critical ingredient or repeating that step.

Presumably, thinking to ask oneself these 'critical decision point' questions and even asking the questions themselves require some, albeit potentially minor, amount of processing time. In turn, it is conceivable that allowing oneself the time, and attention resources, to consider the task goals and instructions may lead to improved execution of a routine task that is at hand. To date however, we do not know of any studies in which a speed-accuracy relationship has been directly examined within the context of action slips. Clark, Rose and Roy (in preparation) however, have found that older adults completed the Slip Induction Task (SIT) significantly more slowly compared to young adults (Clark, Parakh, Smilek & Roy, in preparation) and seemingly as a result they enjoyed increased accuracy.

The SIT was developed by Clark, Parakh, Smilek and Roy (in preparation) as a method of actually causing action slips to occur within a laboratory environment instead of relying on infrequent and potentially flawed recollections of slips in everyday actions. With this task, participants are first taught, with spatially congruent arrow cues, a series of hand movements to targets and a variety of timing measures including, initiation times and movement times are collected. Following a learning phase, participants continue to repeatedly execute the same sequence of hand movements however, occasionally the exogenous (physical location) and/or endogenous (pointed direction) arrow information is altered thus requiring participants to reconcile the unexpected information and at times move to a new target location.

Exogenous cue information is manipulated in the SIT to determine the extent to which the physical location of distracting information may or may not play a role in determining the likelihood of action slips. Buxbaum, Schwartz and Montgomery (1998) have suggested that any external distracters contribute to the elicitation of action errors but more specifically, findings concerning stimulus-response compatibility (Weigand & Wascher, 2005) and the Simon Effect (Simon & Berbaum, 1990) would suggests that the actual physical location of distracting cues may be especially important in determining the induction of an error. The Simon Effect shows that people are faster and more accurate when the physical location of a cue is spatially compatible with the necessary response. In turn, incompatibility of stimulus and response should impede performance and lead to action slips.

Clark, Parakh, Smilek and Roy (in preparation) found that in eliciting action slips within a well-learned task, incompatible spatial cue information was sufficient to induce errors. Further, spatially incompatible cue information, like an arrow pointed left occurring on the right, was especially problematic when the spatial location coincided with the expected target button within the sequence. In other words, when a participant had learned to expect an arrow cue on the right pointing to the right target button but instead the arrow appeared on the right but pointed to another location, young adults made an action slip as they moved over 70% of the time to the expected target button which coincided with the arrow's exogenous information.

This experience is not unique to younger adults. Older adults who executed the identical task exhibited similar error patterns with the arrow cue manipulations however, their accuracy overall was considerably better (Clark, Rose & Roy, in preparation). Moreover, older adults were especially better than younger adults when an alteration to the expected movement sequence involved both exogenous and endogenous changes, referred to as a combined alteration. That is, the arrow cue expected to appear on the right in fact pointed right, but it appeared in a new location and was pointed in a new direction. Interestingly enough, this increased accuracy when confronted with unexpected and often spatially incompatible cues in older adults coexisted with slower initiation times, movement times, and times to complete each sequence compared to what younger adults required. As such, it is possible that unexpected cue information, coupled with a slower pace of task, allows for a better chance of successful interruption of the CS by the SAS at critical decision points within the SIT. A limitation of this hypothesis however is that it is based on a comparison between two, quite different, participant samples – older and younger adults.

To address this limitation, we had a group of young adults complete the SIT, but instead of asking them to do the task as quickly and accurately as possible, we asked them to complete each sequence within 5000 to 7000 milliseconds – the average range of time that older adult participants needed to complete one sequence. We expected that participants would still experience difficulty with the unexpected arrow cue information however, given this slower general pace of task, we hypothesized that fewer errors would be made compared to what has been observed in previous studies. Furthermore, we expected that whatever increase in accuracy might be found in this study would be especially evident when considering propensity for slips on trials which contained a combined alteration.

METHOD

Participants.

Twenty-seven undergraduate students (average 21.4 years of age) participated in this study for credit toward the required research component of Introductory Psychology at the University of Waterloo. All participants were right-handed, had normal or corrected-to-normal vision and hearing and had no history of neurological or psychiatric injury or impairment.

Experimental Design and Procedure.

Participants completed three tasks during this experiment, the Attention Related Cognitive Errors Scale (ARCES), the Sustained Attention to Response Task (SART) and the Slip Induction Task. Tasks completed in that order for all participants and will be discussed in turn below.

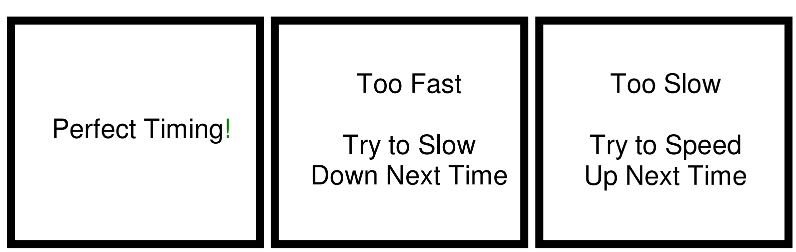
ARCES. Developed by Cheyne, Carriere and Smilek (2006) and partly inspired by the Cognitive Failures Questionnaire (Broadbent et al, 1982) this 12-item self-report questionnaire uses a simple 5 point scale to determine if different attention failures in daily life are encountered never (1) to very often (5).

SART. This computer-based task taxes participants' sustained attention and inhibition abilities by asking participants to view a series of 225 randomly presented digits (one through nine) and to respond with a key press each time they see a digit except when the digit is three. This task is simple on the surface but since it is extremely tedious, it still requires active attention to each digit or participants risk a commission error – a failure to withhold one's response to the target. Due to these requirements Robertson et al (1997) and later Manly, Robertson, Galloway and Hawkins (1999) assert that one's ability to avoid commission errors on the SART reflects one's ability to maintain consciously controlled, or sustained, attention and that it also reflects one's ability to inhibit a learned response.

Slip Induction Task (SIT). This task begins with a learning phase in which participants were randomly assigned to practice the same sequence of seven hand movements to target buttons either 20, 120 or 360 times. Participants learned the sequence by following arrow cues that were spatially congruent with target buttons located either, above, below, to the right or to the left of a central home button. All arrow cues were 70 mm in length (creating a visual angle of between 11° and 16°), 50 mm in height (creating a visual angle of between 9° and 13°) and were displayed 125 mm from the center of the screen in one of four directions.

To encourage participants to complete each sequence of movements within the desired window of 5000 to 7000 milliseconds, each sequence ended with timing feedback that either indicated that the participant had completed the sequence with perfect timing or that they were too slow or too fast (see Figure 4.1). This feedback remained for a variable period of 500 to 1500 milliseconds and as soon as it disappeared, participants were instructed to press the home button to activate the first arrow of the next sequence (beginning the initiation time measure). Upon seeing the arrow cue participants released the home button (ending the initiation time measure, beginning the movement time measure), moved to the target that it pointed to and depressed the target (ending the movement time measure, beginning the button time measure). Participants were asked to then quickly release the target button (ending button time measure, beginning return to home time measure) and move back to depress the home button (ending return to home time measure) to activate the next arrow cue.

Figure 4.1: Timing feedback following completion of a sequence



Upon completion of the assigned practice trials, participants immediately proceeded into the alteration phase of the task where they executed the same sequence an additional 600 times. In this phase they were once again asked to complete each sequence in 5000 to 7000 milliseconds and given timing feedback after each sequence. Within this alteration phase 76% of trials were completed as expected. Twenty-four percent (24%) of the trials were altered such that participants encountered an unexpected arrow cue at either the beginning of the sequence, moves two or three, or at the end of the sequence, moves five or six. Forty-eight of the altered cues either appeared in an unexpected physical position but still pointed to the expected target (positional alteration, see description in Chapter One, Figure 1.1, p.19), anther 48 of the altered cues appeared in the expected physical position but pointed to an unexpected target button (directional alteration, see description in Chapter One, Figure 1.2, p.20), while the other forty-eight altered cues both appeared somewhere unexpected and pointed to an unexpected target (combined alteration, see description in Chapter One, Figure 1.3, p.21). All participants were aware before beginning this phase of the experiment that this altered cue information would occur and the experimenter remained with the participants for the first few altered trials to ensure that all instructions were well understood.

<u>Analyses.</u>

Effectiveness of Timing Feedback. The percentage of sequences completed in the alteration phase within the desired timing window of 5000 to 7000 ms was computed and only those accurately timed sequences were included in subsequent analyses. In addition, the average time to complete altered and unaltered sequences across practice groups was compared using a two (altered versus unaltered) by three (practice group) mixed ANOVA with group as the between subjects factor. This will determine the general speed at which participants completed the sequences (unaltered ST) as well as if speed of task increased for participants who had additional experience with the task during the learning phase.

Induction of Slips and Impact of Practice on Accuracy. In addition to considering pace of task, we used a four (alteration type) by three (practice group) mixed ANOVA with group as the between subjects factor to determine if altered cues in the SIT would significantly cause action slips and whether there would be an impact of experience with the task during the learning phase on accuracy. Three planned comparisons were included to reveal any significant declines in accuracy between trials that contained a positional, directional or combined alteration and trials that were not altered. Also, three additional pair-wise t-tests, with corresponding Bonferoni α-level corrections, were conducted to ascertain whether differences in accuracy between the three alteration types were observed.

Timing Costs Associated with Altered Cue Information. Previous studies using the SIT have found that altered arrow cues result in timing costs with respect to IT, MT and ST (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation). Accordingly, three separate repeated measures ANOVAs were used to detect differences in IT, MT and overall ST between altered trials in which an error/slip was made (level one), altered trials that were completed correctly (level two) and unaltered trials (level three). Two planned comparisons as well as a pair-wise t-test were also included for each of the ANOVA analyses to directly compare correctly executed trials with error trials and unaltered trials.

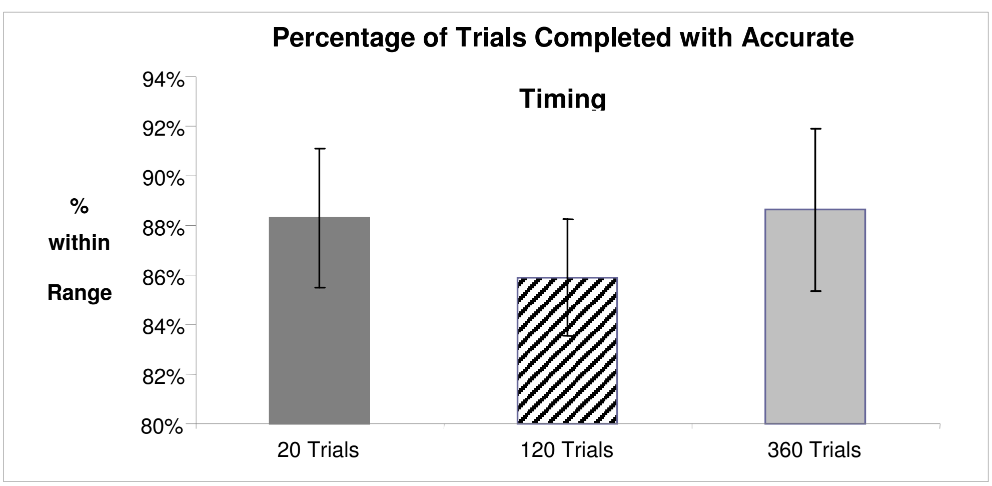
Influence of Task Pace on Action Slips. Consistent with our hypothesis that a slower pace of task would subtend better performance on the SIT, we conducted a series of Pearson correlations to determine if increased STs on unaltered and/or altered trials would be associated with fewer errors overall and specifically, increased accuracy on positional, directional and/or combined altered trials.

Congruence with Other Measures. Lastly, Pearson correlations were computed between inhibition errors on the SART, self-reported attention failures in daily life as measured by the ARCES and errors on positionally, directionally and combined altered trials.

RESULTS

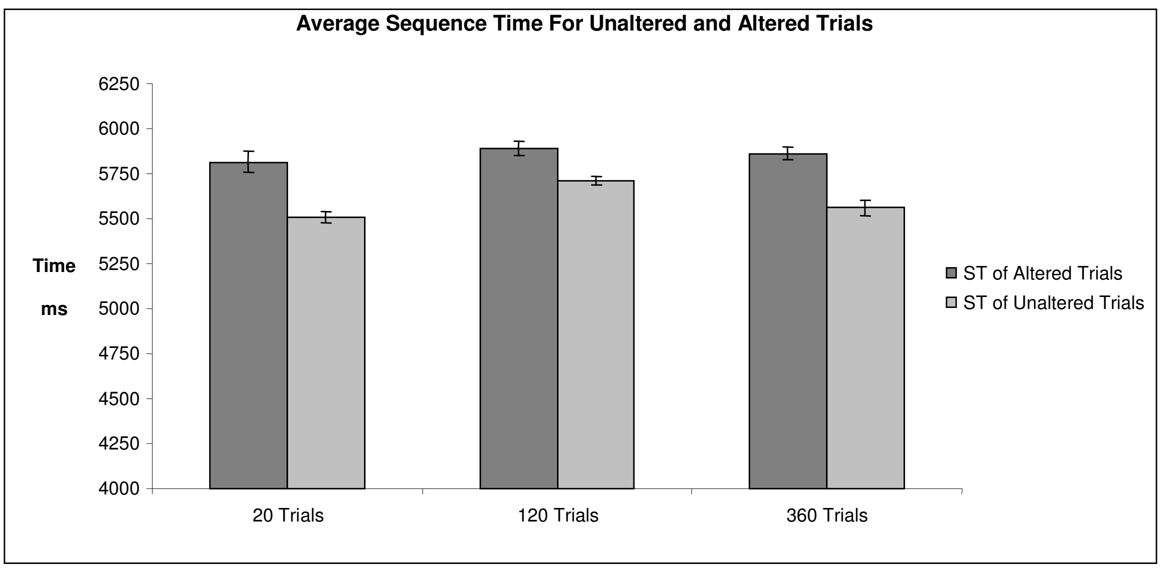
An average of 88% of trials (SD = 8.7%), within the alteration phase of the SIT, were completed inside the desired time frame of 5000 to 7000 milliseconds (see Figure 4.2) and for each participant only these accurately timed trials were included in subsequent analyses.

Figure 4.2: Percentage of Trials Completed within Desired ST Window



We observed that participants completed sequences at the low end of the desired ST range (see Table 4.2 for mean and variability data and Figure 4.3). Furthermore, while we did find a significant main effect of whether a trial was altered or not (F (1, 20) = 20.04, p<0.001) even when a trial was altered, on average, participants were still able to execute that trial in less than 6000 milliseconds. In addition, there was no main effect of amount of practice participants had in the learning phase of the task on this tendency to complete sequences in the lower end of the desired time range (F (2,20) = 2.962, p=0.075), nor did practice amount interact with whether the trial was altered or not (F (2,20) = 2.103, p=0.148).

Figure 4.3: Average STs (in ms) in Practice Groups for Unaltered and Altered Trials

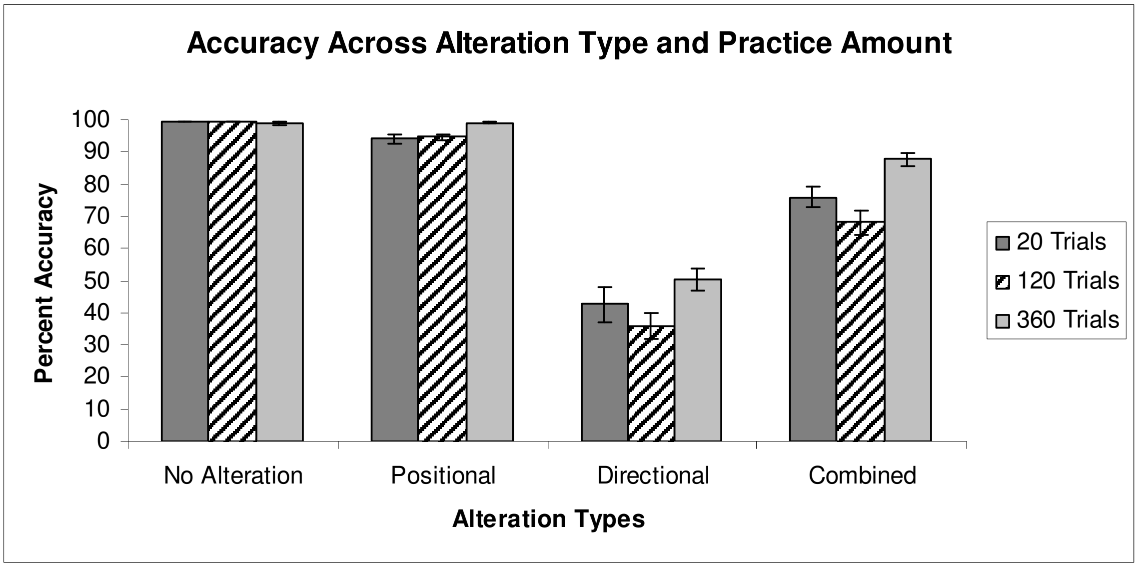


With respect to accuracy (see Table 4.1 for mean and variability data and Figure 4.4), a four (alteration type) by three (practice amount) mixed model ANOVA revealed that participants made a significant number of slips whenever they encountered unexpected cue information (F (3, 17) = 117.06, p<0.001). In fact, simple planned comparisons show a significant decline in accuracy for positionally altered trials compared to trials that were not altered in any way (F (1, 19) = 11.514, p=0.003). Additionally, planned comparisons indicate that anytime altered cues required participants to move to an unexpected target button as is the case for both directional and combined alterations, accuracy was significantly affected compared to unaltered trials. (F (1,19) = 161.10, p<0.001; F (1,19) = 54.03, p<.001; respectively). Interestingly though, a post-hoc paired t-test reveals that despite also requiring a change in expected movement direction, accuracy on trials with a combined alteration was significantly better than on directionally altered trials (t (19) = 10.56, p<0.001). Though significant numbers of action slips were created with all three types of alterations, accuracy on altered trials was not effected by amount of practice in the learning phase (F (2,18) = 2.172, p=0,145) nor did practice interact with type of alteration (F (6,51) = 1.574, p=0.236).

Table 4.1: Descriptive Statistics for Accuracy Data during Alteration Phase

	Unaltered Accuracy		Positional Accuracy		Directional Accuracy		Combined Accuracy		Total Errors: Altered Trials	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
20 Trials	99.60	0.37	93.97	5.93	42.59	24.75	76.01	14.00	34.66	15.66
120 Trials	99.43	0.30	94.52	4.22	36.05	18.13	68.00	16.45	39.63	14.18
360 Trials	98.85	2.09	98.97	1.14	50.25	14.90	87.72	9.35	47.50	23.19

Figure 4.4: Accuracy Data During Alteration Phase

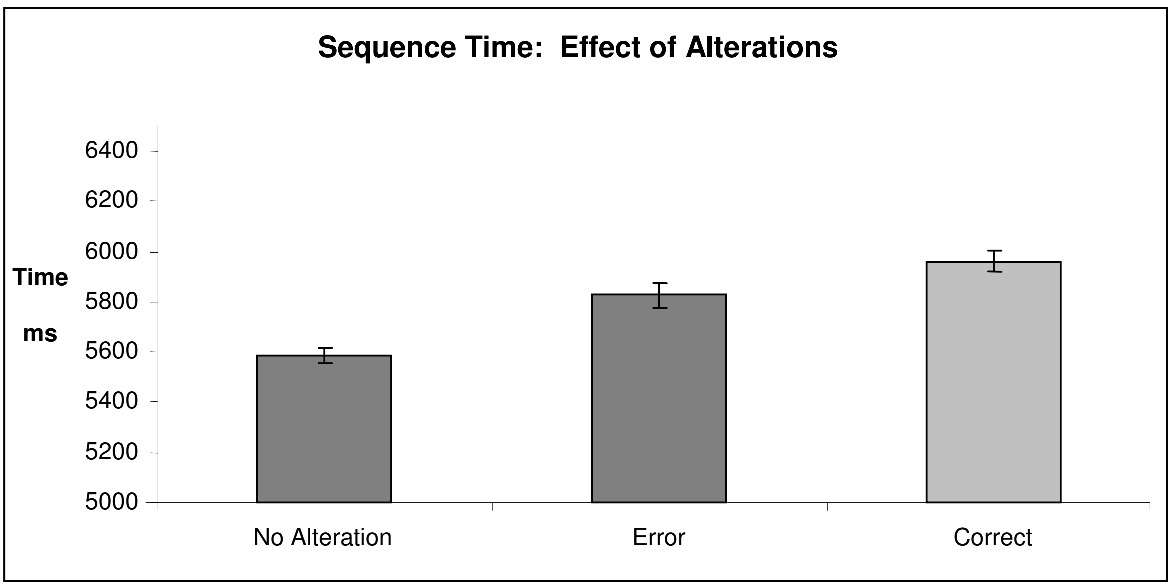


Turning now to the results from the three level (altered trial and error, altered trial and correct, unaltered trial) repeated measures ANOVAs that were used to identify the effects of any type of alteration on measurements of timing, we found that alterations to the expected movement routine also impacted the amount of time required to execute the entire sequence (ST, see Table 4.2 and Figure 4.5). In fact, a main effect of encountering an alteration was observed ($F(2, 46) = 27.55$, $p<0.001$) and further planned comparisons revealed that when an error was made due to an alteration, average ST was longer than when no alteration occurred ($t(23) = 4.664$, $p<0.001$). In addition, when participants were able to complete the movement correctly, STs were even longer than when an error was made ($F(1, 23) = 5.223$, $p=0.03$).

Table 4.2: Descriptive Statistics for Timing Data during Alteration Phase

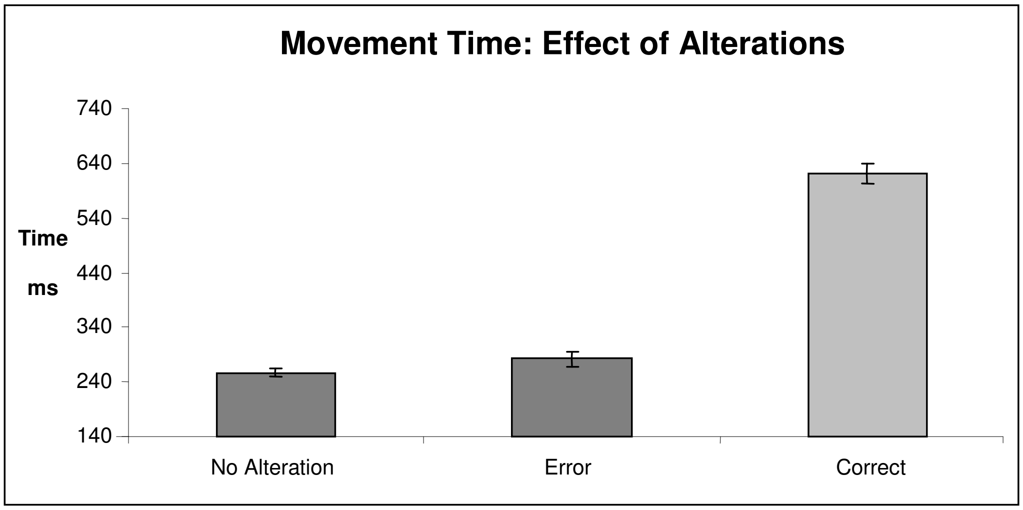
	ST (in ms)		MT (in ms)		IT (in ms)	
	Mean	SD	Mean	SD	Mean	SD
Unaltered Trial/Move	5584.45	156.18	256.29	38.23	138.49	33.63
Altered Trial/Move (combined)	5971.35	333.93	465.15	34.64	130.87	34.64
Altered & Error Trial/Move	5828.73	236.69	281.99	63.33	129.49	33.88
Altered & Correct Trial/Move	5961.92	203.75	620.76	88.52	140.20	38.86

Figure 4.5: Average STs (in ms) Comparing Unaltered Trials and Altered Trials that were Executed Correctly or Resulted in Errors.



Furthermore, while there was no effect of an altered cue on IT, alterations did impact participants' MTs (F (2,46) = 394.94, p<0.001; see Figure 4.6). Also, though MTs for altered trials in which an error was made were longer than when the trial was not altered (t (23) = 2.382, p=0.03), the main effect of alteration is driven by a dramatic increase in MT when the altered trial was completed correctly ($F(1,23) = 425.31$, $p<0.001$).

Figure 4.6: Average MTs (in ms) Comparing Unaltered Trials and Altered Trials that were Executed Correctly or Resulted in Errors.



Surprisingly though, participants' general pace of task did not correlate with frequency of errors on altered trials or individual accuracy on directional, positional or combined altered trials (see Table 4.3). Also, while participants had an average score of 2.79 out of 5 on the ARCES (SD = 0.56), these self-reported attention failures only correlated with accuracy on positionally altered trials on the SIT (see Table 4.4). Further, the number of errors participants made on unaltered trials in the SIT correlated positively with commission errors on the SART (x = 11.41, SD = 4.53) and accuracy on altered trials also trended toward a similar relationship.

Table 4.3: Correlations between Speed of Task and Errors/Accuracy

	Unaltered ST	Altered ST
Altered Errors	r = -0.242, p=0.265	r = 0.168, p=0.411
Positional Accuracy	r = 0.021, p=0.924	r = 0.081, p=0.712
Directional Accuracy	r = 0.237, p=0.276	r = -0.054, p=0.792
Combined Accuracy	r = -0.192, p=0.404	r = 0.092, p=0.670

Table 4.4: Correlations between the SIT and Other Measures of Inattention

	ARCES	SART Errors
Altered Errors	r = -0.147, p=0.536	r = 0.383, p=0.086
Unaltered Errors	r = 0.052, p=0.833	**r = 0.469, p=0.037**
Positional Accuracy	**r = 0.470, p=0.049**	r = 0.275, p=0.254
Directional Accuracy	r = -0.234, p=0.320	r = -0.315, p=0.164
Combined Accuracy	r = -0.246, p=0.310	**r = -0.451, p=0.05**
ARCES		r = 0.308, p=0.214

DISCUSSION

The purpose of this study was to determine if complementary evidence for a relationship between general pace of task and accuracy on an occasionally altered movement routine could be found when young adults were asked to complete sequences within the SIT at a pace which is similar to what older adults typically employ. In previous studies examining the SIT (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation), young adults were observed to complete well-learned sequences of seven movements in an average of 3 to 4 seconds and they were also very affected by unexpected changes to that routine sequence when they were encountered (errors were made on 10 to 70 percent of altered trials depending on the type of change that was required). Additionally, Clark, Rose and Roy (in preparation) recently found that older adults who completed the SIT required substantially more time to complete the well-learned sequences within the task (average ST between 5 and 7 seconds) but enjoyed much improved accuracy when infrequent cue changes were encountered (errors were made on 5 to 30 percent of trials depending on the type of alteration). Taken together, these results suggest that a possible speed-accuracy relationship may exist such that moving at a slower pace during the completion of a routine task allows for better accuracy; possibly because this increased amount of time makes the chance of a successful interruption of Norman and Shallice's (1986) contention scheduling system (CS) by the supervisory attention system (SAS) at critical decision points, where an alteration may have been encountered, within the SIT.

Given that this hypothesis is built on a comparison between age groups, where several other factors are likely to co-vary, this experiment was designed to determine if a similar relationship between pace of task and accuracy would be found when pace was directly manipulated. This was accomplished by asking a sample of young adults to complete each sequence in the SIT within the time range that was observed in the older adults in Clark, Rose and Roy (in preparation).

With the help of sequence timing feedback, which was given to participants following each trial, the young adults within this study achieved very good compliance with the goal of completing each sequence within the desired time range of 5 to 7 seconds and this level of compliance did not improve or worsen with increased exposure to the task. Of note though is that on average, participants in this study still completed most of the sequences in times at the lower end of this range, with very few sequences being completed in more than 6 seconds.

Despite completing the sequences at a slower pace than would be typical for young adults, after the movement sequence became well-learned, participants in this study were still dramatically affected by changes to the expected arrow cue information during the alteration phase of the SIT. Considering the relatively frequent errors that were induced by altered arrow cues, it is safe to assume that after the movement sequence became well-learned participants relied more exclusively on their CS to direct their movements; as such, when changes to the expected movement routine were required, as is the case for directional and combined alterations, accurate completion of the sequence suffered. Like has been shown in other experiments using the SIT, participants in the current study found directional alterations most detrimental to accurate performance, combined alterations induced fewer errors, and positional alterations induced the least action slips. This general pattern of results in the SIT lends support to a theory of stimulus-response compatibility playing a role in the induction of errors. Specifically, since directional alterations were most likely to induce a slip, incompatibility between the physical location of a cue and the endogenous information it contains can be quite problematic during the execution of routine action – especially when a change in movement goal is signaled by a cue that appears in a physical location that is compatible with the expected movement direction.

Participants in this study did make errors when they encountered altered arrow cues but they were more accurate on trials in which the expected goal of a movement changed (43% for directional alterations and 77% for combined alterations), compared to the similarly aged participants from Clark and Roy (in preparation) who completed the task at their own pace (23% for directional alterations and 58% for combined alterations). In fact, when these two groups of participants are directly compared to each other using a four (alteration type) by two (pace group) mixed ANOVA with pace group as the between subjects factor, a main effect of pace group is found such that participants who completed the SIT at a slower, fixed pace were significantly more accurate than those in the self-paced group ($F(1,41) = 13.051$, $p=0.001$). Additionally, a two-way interaction between pace group and alteration type is found ($F(3,123) = 11.587$, $p<0.001$) and post-hoc analyses reveal that this benefit of a slower pace is significant only for trials that contained a directional or combined alteration. However, using a more conservative confidence interval approach, see Table 4.5, average accuracy on directionally nor combined altered trials for participants in this study were outside the 95% confidence interval that is established by the study in which participants did the task that their own pace (Clark & Roy, in preparation). Furthermore, only 41% and 12% of participants fell outside this confidence interval for directional and combined alterations, respectively.

Table 4.5: Comparing Fixed Pace SIT Accuracy to Self Pace Samples

	Average Accuracies from Current Study	Upper Limit of Accuracy CI (Clark & Roy, in preparation)	Percentage of Fixed Paced Participants whose Mean Accuracy Falls Outside of CI
Directional Alteration	42.57	48.35	41%
Combined Alteration	76.72	94.35	12%

Our results also indicate that even though participants were completing the task at a relatively slow pace considering their age, whenever unexpected arrow cue information was encountered, those alterations had an additional slowing effect. Indeed, times to complete the sequence (ST) as well as the actual time to move to the target on that altered trial (MT) were substantially longer when an alteration occurred compared to trials that were not altered in any way. Moreover, this slowly was especially pronounced when participants were able to reconcile the unexpected cue, often needing to inhibit their expected movement plan by allowing their SAS to override their CS and move to the target button that the arrow cue pointed to. This dramatic impact of altered trials that were completed accurately provides converging evidence of a link between the pace of task and accurate movements within a typically routine movement sequence.

However, contrary to our prediction, and what has been found in other studies using the SIT (Clark, Rose & Roy, in preparation; Clark & Roy, in preparation) we did not find evidence of a correlation between the pace at which participants completed sequences (unaltered or altered) in this study and the number of errors that they made when alterations were encountered. We expect however that this lack of a correlation is due to a truncation in the variability of pace that resulted from our prescribed desired time range. Nonetheless, since the accuracy results from the current study, where participants completed the task more slowly, are much better than in previous studies where sequences were executed more quickly, it is clear that pace does influence accuracy. As such, preventing action slips from occurring in a well-learned action routine may be possible, at least in part, through slower task execution.

It is important to recognize however that a slow pace of task, like is seen with older adults (Clark, Rose & Roy, in preparation), was not entirely successful in making the participants in the current experiment as accurate as their older counterparts. In fact, though the participants in this study were more accurate than other young adults that did the SIT at their own pace, average accuracy in this study (43% accurate for directional alterations and 77% accurate for combined alteration) was lower than older adults were able to achieve (72% accurate for directional alterations and 88% accurate for combined alterations; Clark, Rose & Roy, in preparation). There are a few potential explanations for this disparity.

Some might suggest that young undergraduate participants are not as motivated to perform at their best as older adults are. While motivation to perform well is certainly a potential explanation for why the older adult participants achieved higher accuracy scores than the younger adults it is also possible that pace between these two groups was not perfectly equalized. Though we tried to control pace of task in this study by asking participants to complete each sequence in an amount of time that older adults usually require, despite good compliance with this request, the participants in the current study still completed the sequences in the low end of the desired time frame. Though we believe that it is unlikely that this small difference in average pace is responsible for such a dramatic benefit to accuracy in older adults, future study could attempt to better equalize pace by further restricting the desired time frame for young adults.

We think that the most viable explanation for the disparity between accuracies for participants in this study compared to that which has been reported for younger (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation) and older adults (Clark, Rose & Roy, in preparation) is due to a fundamental difference in the task demands between the studies. In previous studies, participants completed the task at a pace at which they were comfortable; a relatively fast pace for the young adults and a relatively slow pace for the older adults. Regardless though, their speed was of their own volition and we would expect that no attentional resources were allocated to the monitoring of task pace. In the current study however, participants were given a dual-task scenario where they needed to execute the sequence of movements while also monitoring their pace on a sequence-by-sequence basis, a task which requires attentional resources. It is possible that this additional task is at least partly responsible for the disparity that exists between accuracy in this study and what has been reported in other SIT experiments.

To address this limitation we suggest that in future studies that consider pace of task, binned analyses could be used to compare participants' pace and its impact on accuracy. Analyses of this type would directly compare accuracies for older and younger adults with an average pace of, for example, 5000 – 5500 ms, 5500 – 6000 ms, 6000 – 6500 ms and so on. Given a large enough sample of participants with a large enough range of average sequence times, analyses of this sort would allow the examination of the impact of pace on accuracy without any overt manipulations of pace being made.

Finally, the observed accuracies for altered trials in this study did not fall outside the confidence intervals established by previous studies in which participants completed the SIT at their own, faster pace. This indicates that further studies should directly compare participants who complete the task at a fixed, slow pace to those that do the task at their own pace. Experiments of this sort would help to conclusively determine if a slower pace of task allows for increased accuracy in situations where action slips are particularly likely.

CONCLUSIONS

The results of this study suggest that even when asking young adult participants to complete the Slip Induction Task within a prescribed range of time, the same pattern of accuracy as that reported in other SIT experiments (Clark, Parakh, Smilek & Roy, in preparation; Clark, Rose & Roy, in preparation; Clark & Roy, in preparation) is maintained. As such, when a movement sequence becomes routine, even when moving relatively slowly, participants are least able to inhibit their expected movement plan when unexpected endogenous information appears in a physical location that is congruent with the expected movement. Further, despite still making numerous action slips, the overall increase in accuracy seen in this study where participants were operating at a generally slower pace than what is typical for young adults, makes it clear that an effective strategy for the prevention of action slips in a well-learned movement routine may be to slow down the speed of task execution. This strategy is likely effective because slowing the pace of task allows the additional time necessary for the supervisory attentional system to interrupt the ‘auto-pilot’ like functioning of the contention scheduling system at critical decision points – before an erroneous movement is made.

CHAPTER FIVE: The Role of Task Goals in Generating Action Slips within the Slip Induction Task

OVERVIEW

Most well-learned activities of daily living are executed through the use of goal-oriented action routines but errors in these routines are surprisingly prevalent. Some have suggested that these errors are the result of insufficient attention to tasks (Robertson et al, 1997) while others have found that an increased frequency of distracters results in increased errors, or slips of action (Buxbaum et al, 1998). We were specifically interested in understanding the role of distracting information in the elicitation of action slips and as such, developed a spin-off of the Slip Induction Task (SIT; Clark, Parakh and Roy, in preparation) in which participants were encouraged to disregard any cue information that was incongruent with the typical movement routine. Consequently, thirty, right-handed, undergraduate participants were taught, with arrow cues, a sequence of seven hand movements to four target locations and participants practiced this same sequence of movements either 120 or 720 times. Following the learning phase, the participants continued to execute the movement sequence however a portion of the sequences contained one arrow cue that was incongruent in some way from what had become expected: either the cue appeared in an unexpected spatial location only, pointed in an unexpected direction only, or both appeared somewhere new and pointed in an unexpected direction. All participants were asked to ignore these infrequent unexpected arrows and thereby maintain their expected movement plan. The results of this study reveal that the task instructions that participants are given dramatically affect their propensity to make errors when unexpected cue information is encountered. In fact, compared to what has been found in studies with the original version of the SIT, where participants were instructed to attend to the unexpected arrows and change their movements when required (Clark, Parakh, Smilek & Roy, in preparation and Clark & Roy, in preparation), participants in the current study were actually less likely to make errors. That is, when participants were actually encouraged to maintain an ‘auto-pilot’ like approach to the task, they had little difficulty doing so, especially if they had had more experience with the task during the learning phase. These results indicate that the type of error committed during the execution of the SIT does depend on the instructions given to the participant. Furthermore, this disparity between the types of error and participants’ propensity to make slips in the two versions of the task indicates that potentially different mechanisms for slips of action may exist.

INTRODUCTION

“Oops! I can’t believe I did that!” - all too often, we experience these points in our day where no other phrase can better describe our actions. Perhaps you are on your way out the door only to realize that your keys are missing from their designated pocket in your briefcase. After 20 minutes of searching, you find them stuffed in a half-emptied grocery bag in the corner of the kitchen. Its only when you find the keys that you remember getting home the evening before, with your hands full of bags, unlocking the door and dropping them as well as your heavy load in the first available place – failing to properly attend to where those pesky keys ended up.

These moments in time, when we find ourselves frustrated and delayed because of situations where our attention has failed us, help to highlight the familiarity that we all have with these types of errors and the repercussions that these mistakes can have on our daily functioning. Errors in routine tasks, like making a cup of coffee or driving a familiar route home from work, have been termed actions-not-as-planned (Reason, 1979) or slips of action. Through a series of diary studies James Reason characterized action slips as resulting from either inadequate action planning (not forming an appropriate goal) or from unintended problems that occur during the execution of an appropriate action plan (Reason, 1977; 1979; 1984; Reason & Mycielska, 1982).

More recent investigations of errors during routine actions have suggested that environmental distracters increase one's proneness to slips (Buxbaum, Schwartz & Montgomery, 1998), that errors are more likely when insufficient sustained attention is allocated to the task (Robertson, Manly, Andrade, Baddeley & Yiend, 1997) and that completing a routine task in a familiar environment makes one especially apt to commit an action slip (Reason & Mycielska, 1982). Broadbent and colleagues (1982) have attempted to explain this propensity to action slips in familiar environments by suggesting that familiar environments contain few attentional demands and as such frees up valuable resources to accomplish extraneous tasks and/or become distracted or bored.

Norman & Shallice's model of action (1986) meshes well with these theories as it purports that with extended experience with a task, we attempt to conserve attentional resources by allowing a contention scheduling system (CS) to control routine tasks in a mostly 'auto-pilot' like fashion. This conservation of resources however has repercussions which include an increased likelihood for errors when changes are required to the routine action. In other words, the supervisory attention system (SAS), which while accurate at controlling action, requires substantial attention resources and makes the real-life demand for dual-tasking nearly impossible. As such, to allow for multi-tasking, the CS is recruited for the execution of well-learned actions which frees up resources for doing other things. But, this creates an increased risk of error in the routine since the execution of the task is not being actively monitored.

This lack of continuous monitoring could be considered beneficial at times though, particularly if it is advantageous to operate in an 'auto-pilot' like fashion thereby ignoring distractions that might creep up during task execution. While writing with respect to selective attention, Tipper (1985; Tipper & Cranston, 1985; Tipper & Driver, 1988) has demonstrated that young adults in particular are able to suppress distracter information with relative ease. They find that young adults show negative priming such that when a task entails finding a target in the presence of distracters, when an item which was a distracter becomes the target on the next trial, participants' response to that item is slowed. This ability to suppress irrelevant information has been shown for a broad range of stimuli including letters, pictures and words (Tipper, 1985; Tipper & Cranston, 1985; Tipper & Driver, 1988; Hasher, Stoltzfus, Zacks & Rypma, 1991) and may also translate into the action domain.

The Slip Induction Task (SIT) was developed to learn more about the precursors and mechanisms of action slips by actually inducing them within a laboratory environment. Studies using the SIT have shown it to be a reliable, effective method for eliciting action errors in routine tasks for both younger (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation) and older (Clark, Rose & Roy, in preparation) adult participants. A key characteristic of the SIT is that a movement sequence to target buttons is trained with spatially compatible directional arrow cues and after the sequence becomes well-learned, occasional deviations to the movement routine are required. In three separate studies using the SIT (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation – discussed in Chapters Two and Four of this document; Clark, Rose & Roy, in preparation – discussed in Chapter Three of this document), it has been found that participants are always most likely to make an action error when the cue that instructs an unexpected movement goal appears in a location that is compatible with where they expected to move at that point in the movement routine. In other words, when a participant expects a cue to appear on the right, instructing a movement to the right target but instead the arrow appears on the right (expected) and points toward the left target (unexpected), participants are especially apt to move to the expected target location rather than what was instructed by the cue.

The current study uses a variation of the SIT to investigate action slips from a slightly different perspective. We had participants complete the SIT in an identical fashion as has been reported in previous studies, with a learning phase first and then an alteration phase where unexpected arrow cues appeared occasionally, but there was one critical difference – we instructed participants to disregard, or ignore, the unexpected arrow cue information and instead, move through the sequence as they had practiced it. At first glance, this variation to the original task may appear minor but in fact, asking participants to actually ignore the altered cues changes a lot about the meaning of the task and the meaning of errors.

In the original SIT, participants are asked to update their expected movement plan to coincide with unexpected arrow cue information and to always move to the target button that corresponds with the pointed direction of the cue. Therefore, when a participant fails to follow the pointed direction of the cue, and instead moves to the expected target button, a slip is committed; likely because they were unable to switch from the 'auto-pilot' like CS to the SAS for control of attention and action. Critically though, in the current version of the SIT, participants are asked to ignore the unexpected cue information and instead move according to their expected movement plan only. Thus, an error in this version of the task would occur when the participant moves to a target button that is different than what is typical (practiced) at that point in the sequence. So, given Norman and Shallice's (1986) theory of the control of action and the contention scheduling system, an error of this sort should not occur under the CS, but only if the task environment is being consistently monitored by the SAS.

We predicted that participants in this study would be apt to conserve attentional resources by using the CS to control their attention and actions while completing the ignore version of the SIT. As such, we hypothesized that they would be able to successfully suppress/ignore the distracting, irrelevant, altered arrow cues, maintain CS control and thereby achieve high levels of accuracy. We did expect however that participants would make some errors during the execution of the ignore version of the SIT but that when such an error occurred it would be the sole result of an inability to suppress irrelevant and simply distracting information. What was unknown was whether participants would make more, less or about the same number of errors due to poor inhibition of *distracting cues* (errors on the current ignore SIT where CS *is not* controlling attention but should be) compared to the frequency of slips that have been reported due to poor inhibition of *expected movement plans* (errors on the original version of the SIT where CS *is* controlling attention but should not be; Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation).

METHOD

Participants.

All thirty participants in this study were recruited via the University of Waterloo's Research Experiences Group and as such received credit toward their psychology course(s) in exchange for participation. Participants were encouraged to volunteer for this study if they were right-handed, between the ages of 18 and 25, had normal or corrected-to-normal vision and hearing, and were healthy with no history of neurological or psychiatric injury or impairment.

Experimental Design and Procedure.

Participants began the experiment by first completing the 12-item self-report ARCES questionnaire (Cheyne, Carriere & Smilek, 2006) in which they rated, on a scale of one to five, how often they experience failures of attention in daily life. Subsequently, the SART (Robertson et al, 1997), a go-no-go task in which the no-go stimulus is rare and randomly occurring, was completed. After the completion of those tasks, participants proceeded to the learning phase of the Ignore version of the Slip Induction Task (SIT) where spatially congruent arrow cues are used to teach participants a sequence of seven hand movements to target buttons. The target buttons are located above, below, to the right and to the left of a central home button and the arrow cues directly movements were 70 mm in length (creating a visual angle of between 11° and 16°), 50 mm in height (creating a visual angle of between 9° and 13°) and were displayed 125 mm from the center of the display in one of the four directions. Participants were randomly assigned to repeat the same sequence of seven movements either 120 or 720 trials, as quickly and as accurately as possible.

Each sequence began with a fixation cross which remained visible for a variable period. When the fixation cross disappeared, participants were instructed to press the central home button which triggered the first arrow cue of the sequence to appear (beginning the initiation time, IT, measure). As soon as the participant noticed the arrow cue, they released the home button (ending IT measure, beginning movement time, MT, measure) and moved directly to the corresponding target button. After pressing the target button (ending MT measure, beginning return to home time, RTH, measure), participants then returned to the central home button where upon depression (ending RTH measure), the next arrow cue was triggered.

Completion of the assigned number of sequences in the learning phase concluded the first day of testing. Five to eight days later, participants returned to the laboratory to complete the alteration phase of the experiment. Following a brief reminder of 60 sequences, participants were instructed that in the next five blocks of 120 trials, most of the time the sequence would go on exactly as they had practiced. However, a portion of the trials contained an arrow cue that was unexpected in some way. Whenever they noticed those altered cues, they were supposed to ignore the unexpected information and move to the target that was typical at that point in the sequence.

A total of 24% of the sequences within the alteration phase of the experiment contained an altered, unexpected arrow cue and this altered cue appeared randomly at any point within the sequence. A totally of forty-two altered cues occurred in an unexpected physical position while still pointing to the expected target button (a positional alteration, see description in Chapter One, Figure 1.1, p.19), seventy altered cues pointed to an unexpected target button while remaining in the expected spatial location (a directional alteration, see description in Chapter One, Figure 1.2, p.20), and twenty-eight appeared both in an unexpected position and pointed toward an unexpected target button (a combined alteration, see description in Chapter One, Figure 1.3, p.21).

Analyses.

The Role of Task Experience.

To determine whether participants would make errors even though they were told to ignore the altered arrow cues as well as whether participants with more experience with the task in the learning phase would be less likely to make errors, a two (practice group; between subjects factor) by four (alteration type; within subjects factor) mixed model ANOVA was conducted. Therefore, accuracy was computed by dividing the number of times participants correctly ignored the positional, directional or combined altered cues and simple planned comparisons were made between accuracy for these alteration conditions and accuracy on trials in which no alteration to the sequence occurred. Also, pair-wise t-tests, with corresponding Bonferoni α-level corrections were used to compare accuracies between the three alteration types.

In addition to considering the impact of practice amount on accuracy, a similar series of three 2 (practice group; between subjects factor) by 4 (alteration type; within subjects factor) mixed model ANOVAs were used to determine how participants' ITs, MTs and overall times to complete an entire sequence (ST) were affected by the type of arrow cue alteration and task experience in the learning phase. Each of these ANOVAs was completed with three planned comparisons to contrast timing of movements altered positionally, directionally, or combined with timing of unaltered trials. In addition, three paired t-tests, with corrections for multiple comparisons, were used to directly compare within the alteration types.

Speed Correlations.

To determine if the speed (ST) at which participants completed the sequence impacted accuracy, a number of correlations were conducted between ST of altered trials, ST of unaltered trials and errors on altered trials as well as individual accuracy for each of the three types of altered trials. In addition, a step-wise multiple regression was used to determine the extent to which practice amount, ST of unaltered and/or altered trials could explain variance in participants' errors on altered trials.

Correlations with Other Attention Measures of Attention Failure.

Pearson correlations were used to determine if performance on the Ignore version of the SIT correlates with commission errors on the SART and/or self-reported attention failures in daily life as measured by the ARCES. Performance measures used from the SIT include, errors on altered trials, accuracy for each of the three types of alterations and errors on unaltered trials.

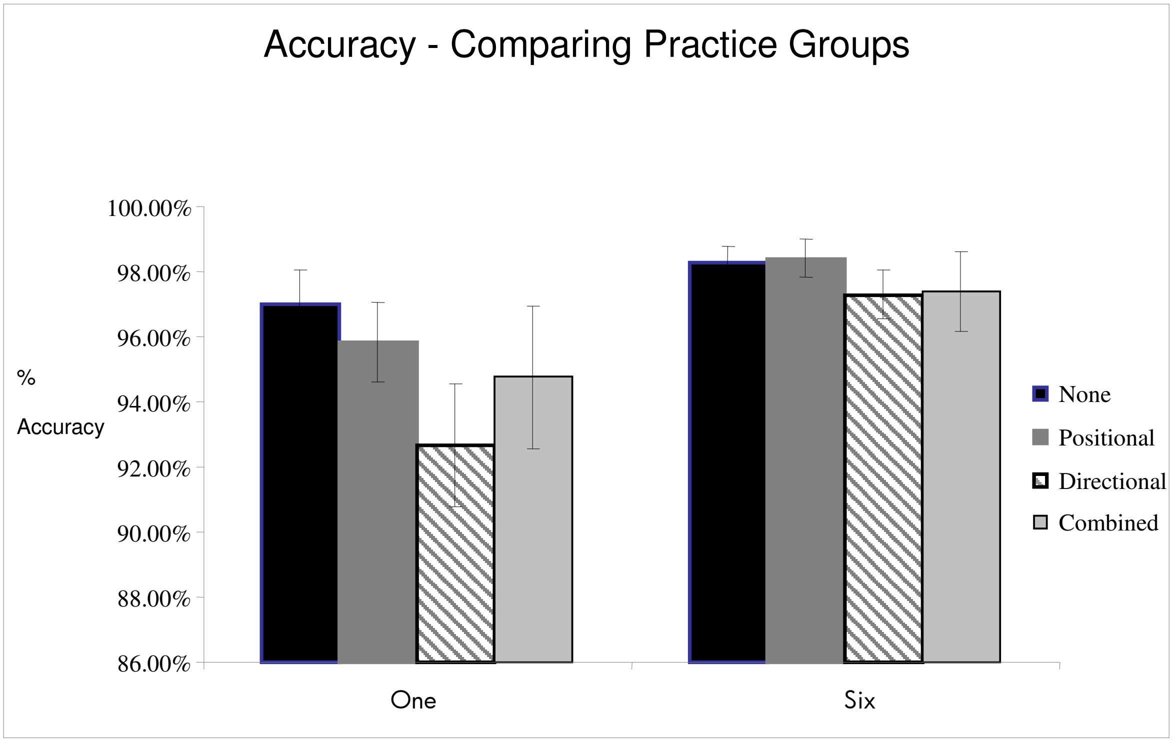
RESULTS

With respect to the Ignore version of the SIT, the results of this study reveal that participants rarely failed to move to the learned target button when unexpected arrow cue information was encountered (see Table 5.1 for descriptive data and Figure 5.1). In fact, while a main effect of altered cue was found, $F(3,22) = 4.03$, $p=0.01$), planned comparisons revealed that it was only when directionally altered cue information occurred that participants made more errors than when the sequence remained unaltered $F(1,24) = 13.13$, $p=0.001$). Furthermore, despite statistically insignificant effects of practice on accuracy, it does appear that those participants with less experience with the task in the learning phase made more errors than those who practiced the sequence more.

Table 5.1: Descriptive Statistics for Accuracy Data during Alteration Phase

	Unaltered Accuracy		Positional Accuracy		Directional Accuracy		Combined Accuracy		Total Errors: Altered Trials	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
120 Trials	96.99	4.05	95.8	4.31	92.68	5.37	94.76	5.78	5.14	1.35
720 Trials	98.27	2.02	98.41	1.55	97.30	2.83	97.38	4.92	2.15	0.56

Figure 5.1: Average Accuracy Comparing Practice Groups and Alteration Type

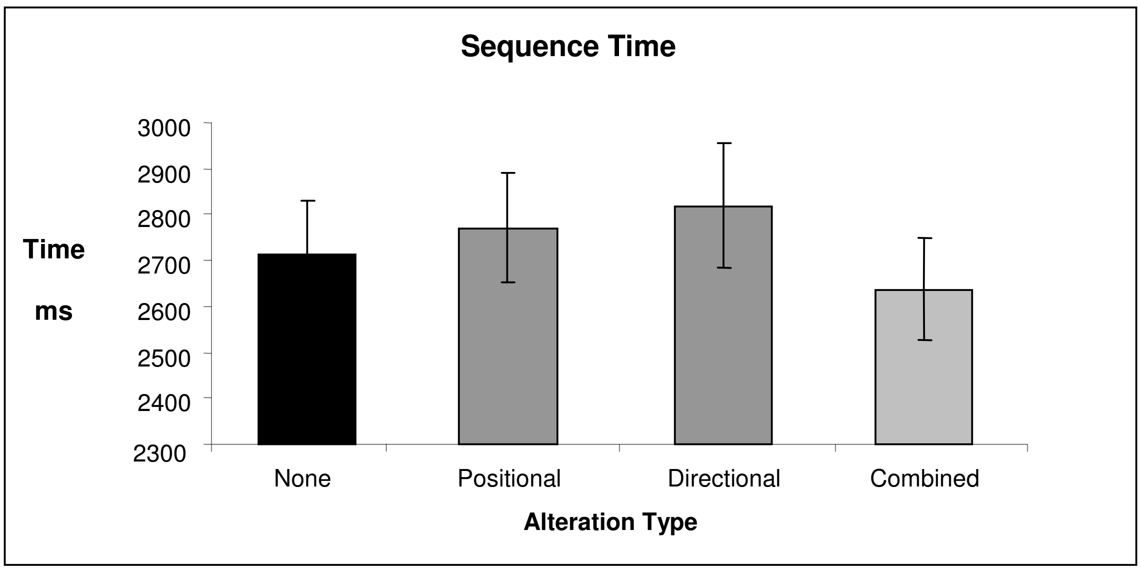


Even though participants rarely made an incorrect movement when they encountered unexpected cue information, it is evident that they were affected by the altered arrows. When comparing the average amount of time participants needed to move through sequences that contained unexpected cues and ST of trials that were not altered in any way, a main effect of alteration is found (see Table 5.2 for descriptive data and Figure 5.2). This main effect reveals that participants required more time to complete sequences that contained altered cue information ($F(3,22) = 10.997$, $p<0.001$). This increase in ST is only observed for positionally and directionally altered cues however ($F(1,24) = 18.90$, $p<0.001$, $F(1,24) = 22.12$, $p<0.001$, respectively) with neither of those two alteration types resulting in larger increases than the other.

Table 5.2: Sequence Time Descriptive Data During Alteration Phase

	ST (in ms)	
	Mean	SD
No Alteration	2712.69	450.77
Positional Alteration	2771.25	459.00
Directional Alteration	2819.28	527.63
Combined Alteration	2637.75	437.39

Figure 5.2: Average ST Comparing Practice Groups and Alteration Type



Contrary to what was hypothesized and what has been found in previous studies using the SIT (Clark, Parakh & Roy, in preparation; Clark & Roy, in preparation), no significant correlation was found between unaltered ST and errors on altered trials or individual accuracies for each of the three types of alterations (see Table 5.3). Instead, it appears that ST of altered trials correlates best with performance on the task such that participants who took more time to complete sequences that were altered were more likely to have made errors on altered trials, and this relationship is maintained for accuracy on positionally and directionally altered trials.

Table 5.3: Correlations between Speed of Task and Errors/Accuracy

	Unaltered ST	Altered ST
Altered Errors	r = 0.308, p=0.126	**r = 0.524, p=0.005**
Positional Accuracy	r = -0.208, p=0.309	**r = -0.450, p=0.019**
Directional Accuracy	r = -0.302, p=0.134	**r = -0.463, p=0.015**
Combined Accuracy	r = -0.106, p=0.605	r = -0.342, p=0.08

Consistent with this pattern of correlations, multiple regression analyses reveal that altered ST is the best predictor of whether participants made errors when altered cues were encountered. Even when entered as the last variable, after practice amount and ST of unaltered trials, altered ST still contributes significantly to the regression model (see Table 5.4). Also of note, even when entered into the model first to absorb the most amount of variance, practice amount was not a significant predictor of errors in the alteration phase.

Table 5.4: Best Regression Model for Predicting Errors

DV = altered errors	R	R square	R square change
Step 1: Practice Amount	0.328	0.108	0.108 p=0.10
Step 1: Unaltered ST	0.406	0.165	0.057, p=0.22
Step 3: Altered ST	**0.615**	**0.378**	**0.213, p=0.01**

Interestingly, even though participants made an average of 12.57 commission errors on the SART (SD = 4.93), SART errors did not correlate with any performance measures from the Ignore version of the SIT (see Table 5.5). In addition, participants' ARCES scores (x = 2.68, SD = 0.41) did not correlate significantly with any of the performance measures from the Ignore version of the SIT.

Table 5.5: Correlations between the SIT and Other Measures of Inattention

	ARCES	SART Errors
Altered Errors	r = -0.016, p=0.938	r = 0.383, p=0.086
Unaltered Errors	r = -0.317, p=0.122	r = 0.138, p=0.500
Positional Accuracy	r = -0.092, p=0.656	r = 0.059, p=0.770
Directional Accuracy	r = -0.012, p=0.953	r = 0.045, p=0.823
Combined Accuracy	r = -0.046, p=0.825	r = -0.333, p=0.089
ARCES		r = -0.105, p=0.589

DISCUSSION

Consistent with our prediction, we found that errors on the ignore version of the SIT were very rare and this likely suggests that participants were effective at maintaining CS attentional control which helped the suppression/inhibition of the altered arrow cues. Nevertheless, some errors on directionally altered trials did occur. This indicates that when a participant encountered unexpected endogenous cue information in the expected spatial position, participants were more likely to interrupt their expected movement plan, and the CS, to move to a different response button. We think that this unique effect of directional alterations is quite interesting, especially considering that it was the alteration type that induced the most amount of errors in studies using the original version of the SIT (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation; Clark, Rose & Roy, in preparation).

An error on a directionally altered trial in the original version of the SIT results when a participant is unable to switch from the expected movement plan, which is controlled by the CS to the SAS which would allow for a change in movement goal. In contrast, an error on a directionally altered trial in the ignore version of the SIT reflects a moment where, despite this being disadvantageous, the CS is interrupted due to some sort of attention capture and an unexpected movement is made. Regardless of the fact that these errors are the result of two dramatically different erroneous processes, directional alterations were the most likely to induce both types.

That being said, directionally induced ignore errors (4% error rate) were substantially less apt to occur than directionally induced errors on the original version of the SIT (75% error rate - Clark, Parakh, Smilek & Roy, in preparation; 77% error rate - Clark & Roy, in preparation). In fact, when directly comparing accuracy on directionally altered trials for participants who were asked to ignore the arrow cues, compared to participants who were asked to follow the arrow cues (from Chapter Two), an independent samples t-test reveals that ignoring arrow cues was significantly easier to complete than following them ($t(58) = 24.233$, $p<0.001$). Indeed, using a more conservative confidence interval approach, see Table 5.6, average accuracy on directionally altered trials for participants in this ignore arrows study was well outside the one-tailed 95% confidence interval that is established for the young adult study that used the original, follow arrows, version of the SIT (Chapter Two).

Table 5.6: Comparing Ignore-Altered-Arrows-Task Accuracy to Follow-Altered-Arrows-Task Accuracy

	Average Accuracy from Ignore Study	Percentage of Ignore Arrows Participants whose Mean Accuracy Falls Outside CI	Upper Limit of Accuracy CI (Clark & Roy, in preparation)
Directional Alteration	96.05	100%	48.35

In addition to its impact on accuracy, the effect of unexpected arrow cues was also found when the amount of time that participants required to complete the altered sequences is considered. While this impact is certainly subtle, whenever participants encountered positionally or directionally altered arrow cues, their STs were longer than when no alteration was encountered. Thus it appears that when participants attempted to suppress distracting information that shared some element with the expected cue, its spatial location (directional alteration) or its pointed direction (positional alteration), this act of suppression required resources (reflected in ST effect). Furthermore when the distracting cue did not share any information with the expected cue (combined alteration), an opposite effect is found when considering participants' MTs where faster movements to the expected target button are observed when the cue is in an unexpected location and pointed somewhere unexpected. With respect to accuracy however, it was only when the cue shared its spatial location (directional alteration) that an error was more likely to occur. The measures that are incorporated into the SIT uniquely equip it to detect these types of effects. Any other task that does not record participant timing during the execution of routine tasks might have missed this interesting result.

While we were able to detect an impact of suppressing distracting cue information on ST, we did not find a correlation between general pace of task (as measured by ST of unaltered trials) and errors. Instead, only ST of *altered* trials predicted likelihood of making errors when the altered cues were supposed to be ignored. This correlation has also been reported in studies with both younger (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation) and older adults (Clark, Rose & Roy, in preparation) in the original version of the SIT. As such, it likely reflects an overall propensity for people to slow down a bit after making an error on an altered trial, thereby bumping up overall ST of altered trials, regardless of what the task instructions are.

We think that the trend toward errors being less likely when participants had more experience with the task in the learning phase is also a very interesting finding. This trend likely indicates that with more practice, the sequence of movements became more automatic for the participants and as such, they used their CS to direct their actions more exclusively. Therefore, they were less apt to interrupt the CS when unexpected arrow cues were encountered and as such, they were better able to suppress the irrelevant cue information. To more directly assess whether increased task experience has an impact on suppression ability, we would suggest altering the Ignore version of the SIT such that instead of all participants doing the task for an additional 600 trials in the alteration phase (which provides a lot of extra practice with the task) participants would only complete 25 or 50 trials in the alteration phase. Such a change would dramatically restrict the number of alterations that each participant would encounter but would make it less possible that an effect of task experience is being washed out because of increased exposure to the sequence in the alteration phase.

A final goal of this study was to determine the degree to which the Ignore version of the SIT correlates with other currently available measures of attention-related errors. We failed to find a correlation between performance on the SIT and errors made on the SART or participants' self-reported frequency of attention-related errors in everyday life. We predicted a positive relationship between these measures, that is, increased distractibility in daily life as measured by the ARCES would predict increased distractibility on the Ignore version of the SIT as well as an increased likelihood of making errors on the SART. Surprisingly though, no evidence for such a hypothesis was observed.

Since such a positive correlation between the SART, ARCES and SIT accuracy, has been reported using the original version of the task (Clark, Parakh, Smilek & Roy, in preparation; Clark & Roy, in preparation), this lack of the predicted relationship suggests that ignoring distracting cue information as is required in the Ignore version of the SIT is fundamentally different from the original version in that it taps into a different type of attention failure. The Ignore version of the SIT specifically requires participants to avoid being distracted by external information, the unexpected arrow cues. The original version, the ARCES and the SART on the other hand may instead reflect one's propensity to internal distractibility. As such, these two types of measures may not be tapping into the same mechanism for attention related errors during routine tasks.

Overall, this study provides support for a hypothesis that several types of action slips are likely to exist, that these different types of slips may be elicited via different mechanisms and potentially different neural substrates within the dorsolateral prefrontal cortex. Further, at least two different types of slips can be induced using the SIT, depending on what instructions are given to the participants. While both versions of the SIT induce errors when alterations to the expected cues were encountered, specifically directional alterations, the type of error that occurs is the result two dramatically different erroneous processes.

The original SIT task has encountered resistance because the conditions under which errors are induced are especially challenging and may not reflect the typical conditions in the real-world which induce slips. The current version of the task may closer approximate the type of action slip that Reason described since no perturbation to participants' expected movements are required. Instead, when errors are induced in this version of the SIT, they are driven exclusively by a failure to suppress irrelevant and simply distracting information.

CHAPTER SIX: General Discussion

The overall goal of this thesis was to develop a better understanding of what slips of action are, why they occur and how they can be prevented during the execution of the Slip Induction Task (SIT). Typically understood to be the result of insufficient attention during the completion of routine tasks, much of what is known about action slips has resulted from a series of diary studies conducted by James Reason (1977, 1979, 1984, Reason & Mycielska, 1982) in which participants were asked to record the details that surrounded situations in which their action(s) did not match their intention. Considering how pervasive, frustrating, and often costly and dangerous (Robertson, 2003) errors of this sort can be, the SIT was designed to provide further insight into the mechanisms of an action slip by actually inducing the errors within a laboratory-based task.

Developed by Clark, Parakh, Smilek and Roy (in preparation) the SIT asks participants to repeat an action sequence until it is highly practiced and subsequently introduces occasional changes to that movement routine. This approach is based on Norman and Shallice's (1986, 2000) model of action, where a supervisory attention system (SAS; novel tasks) and a contention scheduling system (CS; well-learned tasks) interact to control attention and action. The SIT was developed to tax the interplay between the two systems, thereby inducing errors. In other words, when completing the well-learned sequence as it had been practiced, the movement routine would be controlled by the 'auto-pilot' like CS, but when occasional changes to that routine are required, the SAS would need to interrupt the functioning of the CS to change the expected movement plan. If the SAS was not able to successfully interrupt the CS at those critical points where a change was required, an error, or slip of action would be made. Clark, Parakh, Smilek and Roy (in preparation) determined that this approach to inducing errors was sufficient to elicit significant numbers of errors, particularly when the occasional alteration involved participants having to move to an unexpected target location (directional and combined alterations).

This collection of studies was designed to further investigate the SIT as well as to determine what can be learned about action slips though studying performance on the task. First, the experiment discussed in Chapter 2 was developed to replicate Clark, Parakh, Smilek and Roy's (in preparation) findings, as well as to determine the extent to which performance on the SIT correlates with other measures of attention failure. Second, Chapter 3 detailed an experiment which assessed the effects of healthy aging on slip induction in the SIT. In that study, it was revealed that older adult participants were significantly better equipped to avoid action slips but it appeared that they were able to do so by sacrificing speed for accurate performance. Based on this finding, the experiment discussed in Chapter 4 was developed to determine whether young adult participants would also enjoy increased accuracy if they completed the task at a pace similar to that which was observed in the older adults from Chapter 3. Finally, the study in Chapter 5 investigated whether slips can also be induced in the SIT when participants are instructed to ignore the altered arrow cues. This change in the goal of the task was motivated by an interest in learning whether errors induced due to an inability to inhibit expected movement plans are distinct from errors that are induced due to an inability to inhibit distracting cue information. Since the individual results of each of these studies has already been discussed, this chapter will focus on amalgamating the findings and considering how they contribute to more general explanations of how and why action slips occur as well as possible strategies for their prevention in daily life.

The Effectiveness and Efficiency of the Slip Induction Task

Like demonstrated by Clark, Parakh, Smilek and Roy (in preparation) the studies discussed in this thesis have also shown that participants make significantly more errors when they encounter unexpected cue information than when the movement sequence is not altered in any way. Furthermore, while all three types of alterations induced slips, they did so to different degrees. While the frequency of errors induced by combined alterations was less reliable, a pattern of accuracy, where positional alterations induced the fewest errors and directional alterations induced the most, was generally maintained across all four studies. Given this relatively stable effect, the individual impact of each of these alteration types is certainly of interest.

Positional Alterations

Regardless of age, or how quickly or slowly the participants completed the SIT, everyone seemed to find positional alterations relatively easy to manage. While true that positional alterations did induce some errors, it seems that the characteristics of this type of alteration must have protected participants from error in most cases. Positional alterations were unique in that the unexpected aspect of the cue was simply its spatial location. As such, for accurate performance, participants maintained their expected movement goal and maintenance of CS attentional control was actually beneficial for accuracy. Furthermore, the fact that the positionally altered cues did not appear in a physical location along the expected movement path, which would have created additional competition between movement plans according to Tipper, Lortie and Baylis's (1992) theory of action-centered attention, was likely also a factor in preventing action slips on these trials. Consequently, errors that were made as a result of a positional alteration were only possible when one became sufficiently distracted by the cue's stimulus-response incompatibility that the expected movement plan, and likely the CS, was interrupted.

Considering this marked reduction in the likelihood of making errors on positionally altered trials, it is clear that there is something about directional and combined alterations that increased participants' propensity for action slips. Unlike positional alterations, both directional and combined alterations required a change in participants' movement goal. As such, a switch from the 'auto-pilot' CS was required and it appears that this necessity significantly impacted participants' performance.

Combined Alterations

Even though combined alterations did require a change from the expected movement plan, and therefore a switch to the SAS, participants were always better able to manage this switch than when the trial contained a directional alteration. This difference in accuracy between the two types of alterations is particularly enlightening with respect to the conditions under which action slips are likely to occur.

The key difference between directional and combined alterations is that the latter involved the altered arrow cue not only pointing to an unexpected target button, but also appearing in an unexpected spatial location. Since participants were significantly better at responding correctly to these combined alterations, it follows that there must be something about the cue appearing in an unexpected location that facilitates a switch from the CS to the SAS and therefore correct action production. Specifically, whenever a change to the routine movement was required, performance was enhanced by exogenously cueing that change in a physical location that was spatially incongruent with the expected movement. In other words, cueing a movement change was particularly effective when it happened in an unexpected location, probably because less attention was drawn toward the expected target location.

Interestingly, this effect was especially pronounced in Chapter 3 with older adult participants. In fact, older adults were equally accurate on trials with a combined or positional alteration. This suggests that with increased age, participants are especially likely to have attention drawn toward unexpected exogenous information and this tendency can actually be used to protect them from slips of action.

Overall, this finding that, when required, people are better able to change their movement goal in a routine task if that change is cued in an unexpected spatial location, suggests possible strategies for preventing slips in real life. Take for example a bus driver, Frank, who has driven the same route everyday for the past 5 years. If at some point, he is not fully engaged in his driving task and his typically right hand turn is impossible due to a road closure; Frank is liable to find himself in a dangerous situation. To avoid an accident, our findings suggest that signage that alerts drivers of the closure would be best placed in a location other than on the right. Instead, exogenously salient signage in the middle of the road or even to his left would be more effective.

Directional alterations

Unlike combined and positional alterations, directionally altered cues always occurred in the spatial location that was expected for that point in the sequence, a location that was congruent with the expected target button. Given that this is the one feature that separated it from combined alterations, it follows that there is something about a directionally altered cue sharing the physical location of the expected cue that is particularly detrimental to performance. Indeed, while older adults (Chapter 3) and young adults completing the task at a slower pace (Chapter 4) were more accurate on directionally altered trials compared to young adults completing the task at their own pace (Chapter 2), all participants did worst when confronted with directional alterations.

Therefore, regardless of age or pace, when instructed to follow the arrow cues, a cue that pointed in an unexpected direction but appeared in a location that was exogenously compatible with the expected target was often not sufficient at prompting CS interruption. In the experiment discussed in Chapter 5 however, where participants were instructed to basically ignore the altered cues, participants were still most affected by these directional alterations. There is a critical difference between the types of errors that are made in the ignore (Chapter 5) versus follow (Chapters 2, 3 & 4) arrows studies though.

In the Ignore version of the SIT, participants were instructed to ignore the unexpected cue information and instead move only in accordance with their expected movement plan. Therefore, all altered arrow cues are considered distractions and a slip in Chapter 5 occurred when the participant moved to a target button that was different than what was usual at that point in the sequence. So, given Norman and Shallice's (1986) theory of the control of action and the contention scheduling system, an error of this sort should not occur under CS control, but only if the task environment is being consistently monitored by the SAS. Conversely, in the Follow versions of the SIT (Chapters 2, 3 & 4), participants were asked to change their expected movement plan to coincide with unexpected arrow cue information. Therefore, a slip in Chapters 2, 3 or 4 occurred when a participant was unable to switch from the CS to the SAS, thereby failing to follow the pointed direction of the cue, and instead moving to the expected target button. Despite the fact that the errors made on these two tasks are fundamentally different, Ignore version errors identifying a failure to inhibit unexpected cue information and Follow version errors identifying a failure to inhibit unexpected movement plans, participants were particularly challenged by directional alterations but for fundamentally different reasons.

In the original, Follow version of the SIT, when participants encountered a cue that appeared in a spatially expected position, this exogenous information was taken as confirmation that the movement should be completed as expected and no further analyses, requiring the SAS, was necessary. In the Ignore version of the SIT however, if a participant was ever going to make an error and interrupt their expected movement plan, it was likely to happen because the unexpected pointed direction of the cue was sufficiently difficult to inhibit. Inhibition of directionally altered cues may have been especially difficult because the altered cue appeared within the expected movement path. In fact, Tipper, Lortie and Baylis's (1992) theory of action-centered attention states that for any individual movement, participants need to choose from a number of possible movement plans, one plan that is directed toward the correct target, and others that are directed toward the other targets. Their theory suggests that competition between these plans always exists, but the competition becomes elevated any time that a distracter occurs within the movement path toward the correct target button. Considering this theory, it follows that participants might have particular difficulty with distracting arrow cues that appeared between the home button and the desired target (as is the case for directional alterations).

Taken together, the effect of directional alterations across the four studies suggests that in certain circumstances, unexpected endogenous information is sufficient to capture attention (Ignore version), but in other circumstances it is not (Follow version). An important consideration with respect to these results however is that despite directional alterations being most detrimental to performance in all of the studies discussed herein, the degree to which they impacted performance is dramatically different. Within the young adult studies, whenever participants were instructed to follow the arrows (Chapters 2 and 4) slips were induced on more than 55% of directionally altered trials. When the instructions were to ignore the arrows however (Chapter 5), slips were induced on only 4% of trials. Therefore, the likelihood of committing a slip in response to *unattended* endogenous information (Follow version) is greater than that in response to *uninhibited* endogenous information (Ignore version). Taken together, these results indicate that action slips on the two versions of the SIT are fundamentally different and that they may be the result of different routes to error. In addition, these different types of action slips might also be linked to different neural mechanisms within the frontal lobe. Since Chao and Knight (1998) have implicated the importance of the dorsolateral prefrontal cortex during the inhibition of distracting external stimuli it is likely that the Ignore version of the SIT, where the goal is to avoid becoming distracted by the altered cues, also implicates this system. The Follow version of the SIT however requires participants to inhibit their internal expected movement and also program a new movement online. As such, while difficultly with such demands may also point to deficits within certain areas of the dorsolateral prefrontal cortex, it may also involve other frontal lobe systems.

The Simon Effect and Action Slips

Considering the pronounced, and relatively reliable, pattern of accuracy that was observed in the studies discussed in this thesis, it is particularly interesting to explore this pattern within the context of the Simon Effect. This phenomenon suggests that attention is drawn toward the spatial location of a cue, even when said cue is irrelevant to the task at hand. Furthermore, it is this initial draw of attention toward the cue that facilitates movement to a target that is spatially compatible with the cued location. On the other hand though, when the cue and target are not spatially compatible, movement to the target may be negatively affected since attention was actually drawn away from the target location and instead toward the cue.

Coupled with the observed accuracy patterns from the SIT, the Simon Effect lends insight into what circumstances are most likely to induce action slips. Firstly, since positional alterations were least likely to induce action slips, it follows that when no change to the expected target location is required, simply drawing attention to an incompatible cue location is least likely to elicit an error. For example, when a pilot expects a cue to appear on the right instructing him to enter a runway from the right but he is cued to do so on the left instead, his likelihood of making an error by entering from the left is lower than if his instructions required him to deviate from his expected plan.

Conversely though, when a change to the expected target location is required, like was the case for trials with a combined or directional alteration, cueing such change in a location that is incompatible with the expected movement actually facilitates correct movements (as was the case for combined alterations) compared to when the cue is compatible with the expected location (as was the case for directional alterations). In other words, having attention drawn toward a cue that is spatially incompatible with the expected target location is beneficial in facilitating correct action production. Thus, if a pilot expects a cue to appear on the right instructing him to enter a runway from the right but he is actually cued to enter the runway from the left, his likelihood of entering erroneously is reduced if he is cued to do so in an unexpected (incompatible) spatial location.

The Timing Characteristics of Preventing Action Slips

The SIT provides a unique opportunity to consider the microstructure of the timing of movements within an action sequence. Other measures of attention related errors during routine tasks like the Sustained Attention to Response Task (SART; Robertson et al, 1997), the Naturalistic Action Task (NAT; Schwartz, Segal, Veramonti, Ferraro & Buxbaum, 2002) and the Coffee Making Challenge (Giovannetti, Schwartz & Buxbaum, 2007) do not have this capability. Through consideration of IT and MT a reliable effect was found such that a considerable increase in time during the movement phase was observed whenever an altered trial was completed correctly. This increase of approximately 400 ms appears to reflect the time required to first, switch from the CS to the SAS, then second, inhibit the expected movement plan and last, to program the new movement. Since this increase in time is observed during the actual movement phase and not during the movement preparation phase (IT) it is probable that these events (CS to SAS switch, inhibition, reprogramming) happen online.

Interestingly, while the studies discussed here did integrate relatively sophisticated timing measures, it is not possible to rule out alternate explanations for this MT increase. Particularly of note is that the ITs observed in these studies were very fast and likely indicate a tendency for participants to anticipate the upcoming movement instead of a traditional reaction to the cue. If this is the case, then participants were required to deal with unexpected cue information after they had already initiated a movement toward the expected target button, during the MT phase. As such, the increase in MT that is observed in chapters two, three and four may, at least in part, reflect the processing time that was required to actually consider the unexpected arrow cue.

Furthermore, literature on inhibition of return (IOR; Tipper, Howard & Jackson, 1997) may also help to explain the MT slowing that is observed. While this effect is typically observed when considering reaction time, and we only found evidence for slowing with respect to MT, it is certainly possible that movements to a previously reached for target button would also be slowed. However, even with reaction time measures, an IOR slowing effect typically has a magnitude of less than 40 ms. Since only two of the three alterations required a change in movement goal, and only one third of those trials might have involved returning to a previously reached for target, the amount of slowing that this effect could account for is likely less than 10 ms. Therefore, since the average amount of MT slowing was upward of 200 ms, it is very unlikely that the phenomenon of inhibition of return can solely explain the dramatic MT increase that is observed for correctly executed, altered trials.

Impact of Aging on Slip Induction

The results from this collection of studies revealed that older adult participants made substantially fewer errors on the SIT and also reported fewer attention related errors in daily life on the Attention Related Cognitive Errors Scale (ARCES) compared to their younger adult counterparts. While contrary to popular belief, this finding is in line with other reports of attention related errors in older adults, specifically, that they are less apt to engage in task-unrelated mind wandering (Giambra, 1989) and also that they have a decreased ability to suppress distracting information (Hasher, Stolzfus, Zacks & Rypma, 1991). On the surface, one might think that Hasher and colleagues' (1991) finding of poor suppression in older adults would actually lend itself to more frequent attention failures in this group. However, within the confines of the Follow version of the SIT, where it is actually beneficial to allocate attention to typically unnecessary cue information, poor suppression actually appears to have beneficial effects within the task.

This theory that older adults might actually be less prone to slips of action (in some circumstances) due to their decreased propensity to suppress extraneous information would be strengthened if a similar effect was found within another sample of participants with poor suppression ability. Patients with fronto-temporal dementia also have a marked difficulty with selectively attending to important information and suppressing distracters. Should participants with this impairment show a similar effect of better accuracy on the SIT compared to age-matched controls, a supposition that suppression is actually detrimental to SIT performance would be enhanced.

Another possible explanation for why older adults (Chapter 3) achieved better accuracy on the SIT compared to younger adults is that they typically executed the task at a slower speed than the young participants from Chapter 2. Indeed, consistent with Salthouse's (1979) finding that older adults usually favor accuracy over speed while younger adult participants tend to prefer to finish tasks quickly despite sacrificing some accuracy for that goal, we found that older adult participants took an average of 5800 ms to complete unaltered sequences and 6800 ms to complete altered sequences while the younger adults from Chapter 2 finished in 4500 ms and 6000 ms, respectively. Considering this age difference in the general pace at which participants completed the SIT, it is possible that a slower pace was related to an increased likelihood to switch to the SAS when necessary. However, as mentioned in the discussion section of Chapter 3, it remains unclear what the driving mechanism is behind this beneficial relationship between action slips, increased age and slower pace of task. It is quite possible that older adults simply choose to employ their CS less often for routine actions in an effort to avoid errors and the disproportionate use of their SAS has a side-effect of slower responding. On the other hand, perhaps the sole reason for older adults' enhanced accuracy is reduced suppression and the increased processing demands of not being able to suppress competing information forces older adults to complete the task at a slower speed. Further, older adults' ability to handle unexpected arrow cue information might not be related to suppression at all, instead, the reason for a slower speed might be a moot point and that anyone, young or old, can benefit from a reduced pace of task.

In an effort to provide some modicum of clarification to this question, in Chapter 4, young adult participants were given feedback to help them monitor their pace in an effort to complete each sequence in 5 to 7 seconds, the average amount of time that older adults used. The result of this manipulation indicates that while slowing the general pace of task did boost accuracy on directionally and combined altered trials, the young adult participants in this study did not achieve the level of accuracy that the older adults did. While there are several possible explanations for why this was the case, including that the young adult participants had an additional task demand in monitoring their pace, it is likely the case that the actual reason(s) for a slower pace do matter. Whether those reasons are related to suppression ability or not remains up for debate however.

Pace of Task and Propensity of Error

In addition to the observed differences between studies with respect to pace and its effect on accuracy, we also saw reliable correlations between these measures within each of the studies discussed in this paper. For each of the experiments in which participants were instructed to follow the cues (Chapters 2, 3 and 4) a positive relationship, between the amount of time participants took to complete sequences in which no alteration was present (as measured by unaltered ST) and their accuracy on altered trials, was observed. Interestingly however, this relationship between unaltered ST and accuracy was not found in the Ignore arrows study (Chapter 5). Instead, an opposite relationship was observed such that participants who completed altered sequences more slowly actually made more errors overall.

To better understand the nuances of this disparity between the two studies with respect to the correlation between pace and accuracy, it is important to revisit the conditions under which a slip occurs in each of the tasks. Like mentioned earlier, errors on the Follow version of the SIT are apt to occur if the CS is not successfully interrupted by the SAS when changes to the routine action are necessary. Conversely, for the Ignore version of the SIT, errors are only possible if the participant is *not* operating in 'auto-pilot' mode with the CS and instead is subject to occasional distractions. Therefore it seems that regardless of the goals of the task (Follow or Ignore version), a reduced pace appears to facilitates SAS control of attention and action and this method of control is beneficial to accurate performance when the cues are to be followed, but detrimental to accuracy if the cues are to be ignored.

Correspondence with Other Measures of Attention Failure

Considering that both the SIT and the SART are measures of one's ability to inhibit a routine action, withholding a routine response for the SART and withholding a routine movement to a target within a sequence for the SIT, a positive relationship was expected between commission errors on the SART and errors on altered trials in the SIT. Despite reporting such a relationship in Clark, Parakh, Smilek and Roy (in preparation), no correlation between errors on the two tasks was observed in any of the individual experiments described in this thesis. Similarly, we predicted a positive relationship between the SIT and the ARCES such that those who reported more attention-related errors in daily life would also make more errors in the SIT. Interestingly though, while this positive relationship was found in young adults who did the Follow version of the SIT task at their own pace (Chapter 2), this effect was not observed in any of the other studies.

Seemingly these findings, or lack thereof, suggest that the SIT is tapping into a different type of attention-related error than the ARCES and the SART. While it is certainly likely that inhibiting an expected movement plan on the SIT is more challenging than inhibiting a habitual key press or avoiding errors in everyday life, since there is a trend toward a relationship between these three measures, it is also possible that the studies discussed herein simply lacked sufficient power to significantly detect a relationship. Addressing this inconclusive pattern of relationships may be possible with a meta-analysis in which the results of a series of investigations of the SART, ARCES and SIT can be combined to get a better idea of the magnitude of the correlation(s) between the measures.

Nevertheless, the concept of the SIT was inspired not only by work resulting from Reason's diary studies (Reason, 1977, 1979, 1984, Reason & Mycielska, 1982), but also from the Simon effect (Simon, 1990) as well as Norman and Shallice's model of action (Norman & Shallice, 1986, 2000, Shallice & Burgess, 1993). That individual studies within this research project have not reliably produced correlations between the SIT, the ARCES, the SART (which were also inspired by Reason's diary studies) suggests that perhaps the type of attention-related error that is reflected in the SIT is more indicative of Norman and Shallice's (1986, 2000) equally well-established model of action. In other words, the SIT may not reflect the type of situation that Reason's describes as a precursor to an action slip. Instead, the challenge that participants encounter in the SIT when they experience unexpected cue information, provides an opportunity to examine the interplay that takes place between the CS and the SAS during the execution of routine tasks.

The Impact of Practice on Slip Induction

In all the experiments discussed in this paper, a common hypothesis existed such that increased exposure to the SIT (in the form of practice trials in the learning phase of the task) should cause the movement sequence to become more routine and therefore participants should increasingly rely on the CS for controlling attention and action. We hypothesized that this increased reliance on the CS would in turn lead to a decreased likelihood for CS interruption by the SAS and more action slips when alterations to the expected movement sequence were encountered. However, despite designing studies in which the amount of experience participants had with the sequence during the learning phase was manipulated, an effect of practice was elusive throughout this collection of experiments.

Clark, Parakh, Smilek and Roy (in preparation) found no suggestion of an impact of increased practice, during the learning phase, on accuracy. In that study, participants practiced the sequence 120, 360 or 720 times and they suggested that even in the low practice group, the sequence had become sufficiently well-learned that many errors were apt to occur. In response to that study, the experiment discussed in Chapter 2 changed the range of practice trials to either 20, 120 or 360 but while a trend was observed whereby better accuracy on altered trials was achieved for participants with less practice during the learning phase, statistical significance was not found.

Considering the trend toward an impact of practice on accuracy, it is worthwhile to consider other possible explanations for why an effect is not clear. One possible complication for finding this effect with the current SIT approach is that by the time participants are at the end of the 600 trials in the alteration phase, even those in the low practice condition (20 trials) have rehearsed the sequence 620 times. It is quite possible that this basically rendered the sequence very well-learned even for the low practice group and dramatically weakened any opportunity for finding an effect of practice on accuracy. To determine the validity of such a hypothesis a future study should be completed where a much larger sample of participants would complete the SIT and fewer sequences during the alteration phase would be required. In such a design, the alteration phase would consist of only 25 trials and 6 of those trials would contain an altered arrow cue. With this approach, the integrity of the task would be maintained such that 24% of the trials would be altered but the complication of too much additional experience with the task during the alteration phase might be avoided.

Preventing Slips of Action

Taken together, the results of this thesis suggest a few potential strategies for preventing attention-related errors in routine tasks. Firstly, evidence from accuracy patterns, within the context of the Simon Effect, suggests that whenever attention is drawn toward a cue that is incompatible with the desired response location, this stimulus-response incompatibility causes accuracy to suffer. However, it appears that this effect is especially detrimental if the cue is instead compatible with the expected response (the circumstances of a directional alteration). An increased accuracy on trials with a combined alteration indicates though, that should an unexpected movement be required, an action slip is less likely if the movement cue occurs in an unexpected location, that is, incompatible with the expected response, and is also compatible with the new, desired target location. Thus, while unexpected changes in movement goal are most likely to elicit a slip, such errors can be better avoided if the cue for the movement occurs in a location that is incompatible with the expected movement (drawing attention away from the expected location) and instead is spatially compatible with the new, desired movement (drawing attention toward the new target).

Furthermore, evidence from the studies presented in Chapters 3 and 4 indicates that a slower pace of task might also help to prevent attention-related errors in routine tasks when changes to that routine are necessary and a switch from the CS to the SAS is needed. Unfortunately though, adopting a generally slower approach to all tasks is not advantageous since if the task goals require the suppression of unexpected information, working at a slower speed actually induces more errors. As such, to best prevent action slips from poor inhibition of *expected movement plans* (Follow version of the SIT) a slower pace of task is preferred, however, to prevent errors that result from poor inhibition of *distracters* (Ignore version of the SIT), slowing down is actually detrimental to accurate performance.

Overall Contributions of this Collection of Studies

This thesis work has expanded our understanding of what slips of action are, how and why they occur as well as provided insight into potential strategies for preventing such errors. None of these findings would have been possible without the development of the SIT. Previous methods of studying action slips, like diary studies, have been unable to directly manipulate the circumstances leading to a slip (Reason, 1977; 1979; 1984; Reason & Mycielska, 1982). In addition, methods that contained manipulations to the circumstances that elicit an action slip, like the NAT, have been unable to induce slips within a healthy sample, only within special populations (Schwartz et al, 2002; Coffee-Making-Challenge, Giovannetti et al, 2007). Though these studies have their limitations, their contributions are considerable, particularly because they have investigated these attention-related errors within either a naturalistic setting or task.

The SIT has advanced the study of action slips such that intricacies related to how and why these errors occur have been possible to examine. A limitation of this task however is that it is not as naturalistic as previous studies of action slips. As such, a plan to create a more naturalistic version of the SIT is in development. This naturalistic version of the SIT will still contain the complexity that is associated with positional, directional and combined alterations to a sequence of actions, but the actual sequence will be more like one that is experienced in daily life. For example, by using a coffee-making routine and occasionally cueing participants to add, omit or change the order of a movement within the sequence, we hope to maintain the ability to induce action slips within a healthy population while also being able to examine such errors within a more naturalistic task.

An addition, by using the SIT with a variety of participants and task goals, an explanatory model has been developed in which theories of action control, aging, inhibition/suppression and distractibility are united. With this model we are better able to describe the circumstances under which errors are probable and as such, able to suggest the best strategies for preventing such errors in those situations. For example, whether CS action control is desired or not in any given task informs how one balances speed and accuracy. Furthermore, the results from this thesis suggest that a person's age and therefore, their ability to suppress distracting information should also be taken into consideration when determining the best strategies for preventing slips of action in one's daily life.

Finally, a considerable contribution of this collection of studies is that they reveal there is more than one way to experience an 'oops…' moment and the type of attention related error that a person is prone to is likely characteristic of the individual. Specifically, how one values speed versus accuracy, one's tendency toward internal versus external distractibility and/or one's predisposition to focus attention on one or multiple tasks at a time certainly relates to one's propensity to action slips as well as the type of slip that they are likely to commit.

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