THE COGNITIVE PROCESSES UNDERLYING ROUTINE AND NOVEL NATURALISTIC ACTION PERFORMANCE: EXAMINING THE ROLE OF EXECUTIVE FUNCTION AND MEMORY

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Abstract

Naturalistic actions are multistep activities involving the manipulation of objects to achieve a goal. They can either be routine actions (NA) performed many times or novel actions (NNA) unfamiliar prior to instruction. The aim of this study was to examine and compare the role of memory and executive function in NA and NNA enactment and explore the neuroanatomical substrates involved in enactment performance. Individuals with stroke have been shown to be impaired in NA and NNA performance, which can prevent them from living independently. Thus, this research aims to better inform rehabilitation efforts targeted at improving functionality in these patients. In order to investigate these questions, the relationship between NA and NNA performance and memory and executive function measures was examined in stroke participants and healthy older adults. In Experiment 1, participants were asked to view and perform a NNA over three learning trials. As expected, NNA performance improved across trials. In comparing NAs and NNAs, stroke participants performed better on NNA Trial 1 than NA enactment whereas controls showed the reverse pattern. Hierarchical regression analysis demonstrated that associative memory predicted NNA omission (omitted a step) error rate whereas episodic memory predicted NA omission error rate. Commission (committed a step in error) error rate was not predicted by neuropsychological measures. In Experiment 2, the role of executive function in NNAs was further investigated by dividing attention either at encoding or retrieval of a NNA. Stroke participants were divided into high and low error producers. Overall, participants made more errors when attention was divided at encoding. Although high error producers did not exhibit differentially poorer performance than low error producers and controls, they had significantly longer NNA completion times when attention was divided at retrieval, suggesting difficulties with task switching. Experiment 3 examined the influence of lesions on NA and NNA enactment. Results suggest a role of the extended hippocampal-diencephalic system, prefrontal cortex, and basal ganglia in naturalistic action performance. In summary, behavioural and neuroimaging findings from this study demonstrate that episodic memory, associative memory, executive function and motor-procedural memory are involved in NA and NNA performance.

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Chapter 1: General Introduction

Naturalistic Actions

Naturalistic actions are goal-directed, multistep actions requiring the manipulation of objects to achieve a goal. *Routine* naturalistic actions (NAs) are types of actions that are familiar to the participant and have been performed many times over the course of a person's lifetime. NAs include tasks such as making a cup of coffee or preparing a sandwich. In contrast, *novel* naturalistic actions (NNAs) are unfamiliar tasks that have not been performed prior to instruction. They include tasks such as building an arts and crafts type project (e.g., making an ear guitar), learning how to use an MP3 player, or learning how to manoeuver a wheelchair down a hallway. Individuals in the following study learned these new tasks through observation, which has been established as a primary method of learning (Bandura, 1986).

Similar to activities of daily living (ADLs), naturalistic actions such as using a razor to shave or preparing a meal are functionally important in maintaining self-sufficiency. Accordingly, the study of naturalistic actions may have important clinical and theoretical implications. Naturalistic actions are clinically important because individuals with neurological damage such as from a stroke or a traumatic brain injury have been shown to be impaired in the performance of NAs (Buxbaum, Schwartz, & Montgomery, 1998; Giovannetti, Libon, Buxbaum, & Schwartz, 2002; Schwartz et al., 1999; Schwartz et al., 1998) and NNAs (Martin, 2012; Park et al., 2012). Consequently, impairments in naturalistic action performance may prevent these individuals from living independently, resulting in both a personal and societal burden. From a theoretical standpoint, NAs and NNAs are used to inform theories of action, such as the cognitive processes involved in multistep goal completion tasks (Botvinick & Plaut, 2004; Cooper, Schwartz, Yule, & Shallice, 2005).

This study seeks to further investigate the neuropsychological processes involved in NA and NNA performance, with the aim of developing a clearer cognitive model of goal-directed, multistep action. This study will be guided by previously published research, relevant theory, as well as findings from Lombardi (2007) which examined NA and NNA performance in a group of participants with stroke and aged-matched controls. As will be shown in the next section, this work suggests that memory and executive functioning may be associated with the performance of NAs and NNAs. In addition, previous research has shown that NAs and NNAs may involve overlapping yet distinct cognitive processes (Park et al., 2012). Thus, the primary objective of this study is to further examine the role that executive function and memory for new information (i.e. learning) play in NA and NNA performance, as well as explore neuroanatomical substrates that may be involved in naturalistic action performance.

The investigation of memory in this study was focused on examining the roles of episodic and associative memory in NA and NNA enactment. For the purposes of this study, the term *episodic memory* is defined as recall of previously presented material (e.g., how many times the demonstrator in the video overlapped the string against the ruler). Although the usage of this term may be somewhat different from that of other investigators who define episodic memory as memory for autobiographical events (e.g., Tulving, 1972), this definition is consistent with that of other investigators of naturalistic actions (e.g., Giovannetti et al., 2008; 2012; Park et al., 2012). Further, *associative memory* is defined as memory for relationships among items of information (Troyer, Murphy, Anderson, Hayman-Abello, Craik, Moscovitch, 2008). Both episodic memory and associative memory are *declarative* or explicit forms of memory, where each can be consciously recalled (Squire, Stark, & Clark, 2004).

Naturalistic action enactment.

Routine naturalistic actions. NA performance has been examined in a group of studies of patients with various neurological disorders such as left hemisphere stroke (Buxbaum, et al., 1998), right hemisphere stroke (Schwartz et al., 1999), traumatic brain injury (Schwartz et al., 1998) and dementia (Giovannetti et al., 2002). Overall, these studies showed that patient performance was better predicted by measures of general cognitive functioning than by hemisphere of stroke or lesion location. Remarkably, a detailed analysis of error patterns of NA performance showed that different patient groups in these studies produced a similar proportion of different types of errors (i.e., reversals, object substitutions, omissions: for a summary, see Schwartz, 2006). Several studies including the current study have aggregated specific error types into two broad categories: commission and omission errors. *Commission* errors are defined as an action that is executed incorrectly, for example, a reversal of one or more steps of a sequence. In contrast, an *omission* error is an action that was not attempted. Analyses showed that omission but not commission errors were found to be a predictor of NA enactment (Buxbaum et al., 1998; Giovannetti et al., 2002; Schwartz et al., 1998; 1999). Cooper et al. (2005) reanalyzed the patient data presented by Buxbaum et al. (1998) and Schwartz et al. (1998; 1999) and showed that low error producers tended to make more commission than omission type errors, whereas high error producers tended to produce more omission than commission type errors in NAs. In addition, Giovannetti et al. (2008) showed that omission but not commission errors were associated with level of general cognitive functioning.

Evidence suggests that commission and omission errors may involve different cognitive processes. A study by Giovannetti, Schwartz, and Buxbaum (2007) healthy participants learned a complicated coffee making task which required them to make two cups of coffee in two different ways, using different objects, across several trials. This experiment compared enactment performance from an early practice trial to enactment in a divided attention condition. There was a dissociable pattern of performance across the two conditions (i.e., inexperience vs. divided attention), where participants in the early practice condition were more likely to omit a step whereas participants in the divided attention condition tended to make more commission than omission type errors. The authors concluded that different patterns of performance could be elicited by disruptions to different cognitive processes.

The relationship between different error types and neuropsychological test performance was investigated in a sample of patients with schizophrenia (Kessler, Giovannetti, & MacMullen, 2007) and dementia (Giovannetti et al., 2002). Findings showed that measures of general cognitive functioning were related to omission errors (Kessler et al., 2007), whereas measures of executive function were significantly related to commission errors (Giovannetti et al., 2002; Kessler et al., 2007). Giovannetti et al.

(2008) demonstrated that omission and commission errors were uncorrelated to each other and were predicted by different neuropsychological tests. Specifically, omissions were best predicted by measures of general cognitive functioning and episodic memory performance, whereas commission errors were predicted by a measure of executive control and working memory. A recent study examined the relationship between NA enactment and neuropsychological test performance using hierarchical regression analysis. Results demonstrated that omission errors were significantly predicted by measures of episodic memory, whereas commission errors were predicted by both measures of general cognitive functioning and executive functioning (Giovannetti et al., 2012). Taken together, these finding provide evidence that several distinct cognitive processes including episodic memory and executive function may be involved in NA performance.

It is important to note that in the current experiments, in addition to other research completed by our lab, NA performance was examined for both *crux* (i.e. central action) and *noncrux* (i.e., enabling or housekeeping action) actions. This is in contrast to most previous studies with NAs, which solely investigated the major steps of each action (though see Schwartz, Reed, Montgomery, Palmer, & Mayer, 1991). Cooper and Shallice (2005) have proposed a cognitive model of how NAs are represented in memory in which they hypothesized a hierarchical goal – subgoal structure, where lower level actions that comprise subgoals are required for achieving higher level goals. In the case of the coffee making task, one subgoal is to place a coffee filter into the coffee chamber of the machine. Thus, the participant is required to pick up a coffee filter (noncrux action) and then place the coffee filter into the machine's coffee chamber (crux action).

Novel Naturalistic Actions. NNAs have not been as extensively studied as NAs. In the present study, NNA performance was investigated for both crux and noncrux actions. In the case of the ear guitar task, a NNA used in this study, one of the primary subgoals is to make a hole in the Styrofoam cup with a pencil. The participant is therefore required to pick up the pencil (noncrux action) and use it to pierce a hole through the cup (crux action).

Investigators (Gold & Park, 2009; Park et al., 2012) have observed that crux actions may have more associative linkages between objects, targets, and actions than noncrux actions. Therefore, a disruption to efficient encoding would be more likely to lead to a partial, but incomplete memory trace, for crux than noncrux actions. For example, there may be memory for part of a crux action (e.g., make a hole in a cup), but not the details associated with other parts of that crux action (e.g., what object is used to make the hole). Consequently, this could result in the crux action being attempted, although not executed correctly. In other words, crux actions are more likely to be committed in error than omitted. For example, in the ear guitar task, a subject could remember that they had to make a hole in the cup, but be unsure as to which object to use. They may use the pencil instead of the pin to make a hole in the cup, which would result in an object substitution (i.e., commission error). In contrast, an incomplete memory trace of a noncrux action, composed of only one association between object and action (e.g., take pin), would be more likely to result in an omission of that action.

Park et al. (2012) investigated the effects of familiarity on NA and NNA performance. The authors hypothesized that similar cognitive processes were associated with both types of action, but that memory may be more strongly correlated with NNAs than NAs because objects are used in unfamiliar ways (e.g., a pencil was used to poke a hole through a cup) and a novel sequence of actions must be encoded into memory during viewing and then physically produced. Overall, the authors found that although both NA and NNA performance was lower in the group impaired on a measure of general cognitive function compared to the unimpaired group and controls, participants showed different patterns of performance across the two action types. Specifically, the impaired group had higher omission than commission crux action error rates for NAs, but the reverse pattern for NNAs.

Park et al. (2012) investigated the association between NA and NNA performance and neuropsychological test scores. Results showed that NA omission error rates were more strongly associated with a measure of general cognitive function, consistent with previous research (Giovannetti et al., 2008). In contrast, Park et al. (2012) showed that higher commission error rates were significantly correlated with lower executive function and associative memory scores for NNAs but not NAs, when controlling for general cognitive functioning. Although findings for NAs were not significant, the effect size of the correlation between Trails B, a test of alternating attention, and NA crux commission error rates was comparable to those observed by Giovannetti et al. (2008); thus suggesting that executive function may play a role in both types of action, but that it may more strongly associated with NNAs. Park et al. (2012) concluded that associative memory may be required in NNAs because it is necessary to encode the associations between actions and objects into declarative memory (Gold & Park, 2009; Park et al., 2012; Roy & Park, 2010). Taken together, these findings suggest that although NAs and NNAs involve overlapping cognitive processes, memory and executive functioning appear to have a stronger association with NNAs.

Lombardi (2007) examined the role of lateralization in NA and NNA performance. Analyses revealed that while patients with left (LHD) and right hemisphere damage (RHD) were similarly impaired on NAs and NNAs, patients with LHD made more omission than commission errors on NAs and NNAs, whereas, patients with RHD showed the reverse pattern for both types of action. These findings suggest that although overlapping processes may be involved in NA and NNA performance, NNAs may also recruit different cognitive processes, possibly including those involved in the viewing and encoding of action. In addition, differences in error patterns across both patient groups (i.e. LHD vs. RHD) indicate that omission and commission type errors may be indicative of different cognitive deficits.

Studies have shown that patients with prefrontal cortex (PFC) damage had difficulty segmenting action sequences into meaningful events (Zalla, Plassiart, Pillon, & Sirigu, 2001; Zalla, Pradat-Diehl & Sirigu, 2003). Specifically, they were impaired in the detection of large goal-directed discrete units of action as compared to smaller units. Similar findings were observed when patients with PFC damage were asked to sequence scripts of everyday action such as making a cup of coffee (Sirigu et al., 1995).

Current study. In summary, several studies have shown that although episodic memory, associative memory and executive function are both involved in NAs and NNAs, these cognitive processes may be more strongly implicated in NNAs than NAs (e.g., Lombardi, 2007; Park et al., 2012). The primary objective of this dissertation was to further examine the role executive function and memory play in NA and NNA enactment. This was done through the analysis of participant NA and NNA enactment data in the context of performance on a battery of neuropsychological tests including composite measures of episodic memory and executive function as well as a measure of associative memory. Composite measures for episodic memory and executive function neuropsychological test measures were derived in order to increase measurement sensitivity and minimize the number of multiple comparisons, thereby decreasing the possibility of Type 1 error (i.e., false positive error which fails to reject a true null hypothesis).

In addition, the current study aims to begin to identify the neuroanatomical substrates involved in learning and performing NAs and NNAs by looking at stroke participant enactment of NAs and NNAs in relation to corresponding neuroimaging data. In this way, this study may provide a framework from which to infer the involvement of particular cognitive and neural processes associated with NA and NNA performance. Taken together, the following research will contribute to a greater understanding of the cognitive processes, particularly memory and executive function, involved in NAs and NNAs. In order to investigate these questions, NA and NNA performance in 34 participants with stroke as well as 34 age- and education- matched healthy older adults were examined in a series of three experiments.

Experiment 1 investigated the role of episodic memory, associative memory and executive function in learning NNAs by comparing NNA performance in 16 participants with stroke and a group of 16 age- and education-matched controls to performance on neuropsychological test measures across three study and test trials. In addition, this experiment explored the relationship between NA and NNA performance patterns. This was done by examining stroke patient performance on episodic memory, associative memory, and executive function measures and enactment of NAs and NNAs for all three trials.

Experiment 2 further explored the role of executive function, episodic memory, and associative memory in 18 participants with stroke as well as 18 age- and education-matched controls by manipulating attention either during study or performance of a NNA. Previous research with NNAs, which investigated the role of attention in a group of undergraduates, found that dividing attention at encoding significantly impaired NNA enactment compared to full attention conditions (Gold & Park, 2009). The authors hypothesized that associative memory may be more strongly associated with NNA performance when attention was divided at encoding. They proposed that performing a secondary task while encoding a NNA led to a disruption in the formation of associative linkages between object, target, and action, which resulted in an increase in commission error production. The current study further investigated the role of memory and executive function in NNA, particularly when attention was divided, by examining NNA performance in relation to scores on neuropsychological measures of episodic memory, associative memory, and executive function.

Experiment 3 examined the relationship between areas of brain injury and resulting NA and NNA performance. Patient scans (CT/MRI) were analyzed to determine whether particular brain regions were associated with impaired NA and NNA enactment performance. A finding that damage to specific neural regions (e.g., hippocampus, thalamus, and prefrontal cortex) was associated with impaired NA and NNA performance would support the hypothesis that memory and executive function are important in NA and NNA performance.

All participants were instructed to enact NNAs shortly after viewing a demonstration of each NNA. NAs were enacted without a prior demonstration. Further, all participants, including participants with stroke and controls were administered a neuropsychological test battery that included measures of mental status, language, executive functioning and memory in order to compare NA and NNA performance with functioning across several cognitive domains. Participant NA and NNA enactment performance was assessed by three primary dependent measures: accomplishment, omission error rate, and commission error rate for both crux and noncrux actions. An accomplishment score was calculated by counting the total number of actions (crux and noncrux) that were correctly executed out of the total number of possible actions for that task, multiplied by 100. Similarly, omission error rate was derived by taking the number of actions that were never enacted out of the total number of possible actions within the NNA or NA multiplied by 100. Finally, the commission error rate was determined by taking the number of actions that were executed erroneously out of the total number of possible actions within the NNA or NA multiplied by 100. All three scores were calculated separately for both crux and noncrux actions. I used percentages rather than counts to compare crux and noncrux action performance because there were more noncrux than crux actions.

Chapter 2: Learning Novel Naturalistic Actions in Stroke and Controls (Experiment 1)

Introduction

As described in Chapter 1, previous results suggest that both executive and declarative memory processes may be required to encode NNAs into memory (Gold & Park, 2009; Park et al., 2012). However, at this point, I am unaware of any published study that has investigated memory acquisition of NNAs through an examination of the effects of learning trials on the enactment of NNAs. One purpose of this experiment was to investigate the role of executive function and memory in NNA performance across three learning trials.

A second general purpose of this experiment was to investigate similarities and differences in the cognitive processes associated with the performance of NAs and NNAs. Previous research suggests that similar cognitive processes are involved in the enactment of NAs and NNAs, but that associative memory, a type of memory required in the formation of associations between two distinct stimuli such as an object and an action, may be more strongly associated with memory for NNAs compared to NAs.

Proposed Analyses and Predictions

Effects of practice on NNA performance. A study looking at NNA enactment performance in a sample of stroke patients showed that omission errors were significantly correlated with measures of general cognitive function, whereas, commission errors were significantly correlated with lower executive functioning and associative memory scores (Park et al., 2012). Thus, given findings from previous research with NNAs, one of my main hypotheses was that NNA Trial 1 (T1) accomplishment and omission errors would be significantly related to measures of declarative memory (i.e., episodic and associative memory), while commission errors would be significantly correlated with measures of executive function and associative memory in stroke patients. In addition, I hypothesized that with additional study and test trials, NNA performance would improve and begin to resemble NA performance. In other words, with practice, NNAs would become more familiar and the cognitive processes mediating NNA performance would gradually resemble those involved in NA enactment. Learning in participants with stroke would be demonstrated by improved accomplishment scores across NNA trials as well as by a decrease in the total number of errors. Furthermore, I hypothesized a relative decrease in the *proportion* of commission to omission crux action errors across learning trials, and NNA performance would begin to resemble that of NA performance (Park et al., 2012). This may be due to improved memory for associative linkages between target objects and related actions mediating NA and NNA performance (i.e., Gold & Park, 2009; Park et al., 2012).

The cognitive processes mediating naturalistic action performance across multiple trials was investigated by examining the relation between NNA enactment and performance on neuropsychological tests. The strength and direction of the correlations for NNAs were compared to the association between NA enactment and neuropsychological test performance. Specifically, the relation between participant patterns of performance on each NNA learning trial and performance on neuropsychological test measures was compared to the correlation patterns between performance on NAs and neuropsychological assessment measures. Previous research has shown that general cognitive function was significantly correlated with omission error rates for both NAs and NNAs (Park et al., 2012). Further, the authors found that omission error rates were significantly correlated with executive function and declarative memory measure for NNAs, but not NAs. Park and colleagues also found that higher commission error rates were significantly correlated with lower associative memory scores and executive function scores for NNAs, but not NAs, suggesting that associative memory is more strongly associated with NNAs than NAs.

Several studies support the hypothesis that executive function may play an important role in the enactment of NAs (Giovannetti et al., 2008; 2012; Park et al., 2012). These studies showed that higher NA commission error rates were associated with lower scores on executive function measures (Giovannetti et al., 2008; Kessler, et al., 2007) suggesting that executive function may be necessary for the planning and sequential execution of task steps (Giovannetti et al., 2008; Giovannetti et al., 2012). Although the correlations found between NA crux commission error rates and measures of executive function were not significant in the Park et al. (2012) study, they were roughly comparable in effect size to those reported by Giovannetti et al (2007; 2008) and Kessler et al. (2007). Taken together, these findings suggest that executive functions may play an important role in both NAs and NNAs. Thus, I hypothesized that NA omission error rates would be more strongly associated with measures of declarative memory than with executive function.

The acquisition of NNAs was examined across three study trials and its relation to performance on neuropsychological measures of episodic and associative memory and executive function in a group of participants with stroke and a group of age-matched controls. Sixteen participants with stroke with either LHD or RHD were required to view and subsequently construct four NNAs (i.e., bird feeder, door hanger, mock volcano, and ear guitar) across three trials at full attention. Preliminary analyses of age-matched controls' enactment accomplishment performance showed that under full attention, T1 performance was at ceiling and comparable to healthy younger controls (i.e., Gold & Park, 2009). As such, T1 performance of the control group was used as a basis of comparison for stroke performance. Both groups were also required to enact two NAs (i.e., making coffee, preparing a card) without a prior demonstration.

Method

Participants.

Stroke participants. Sixteen stroke patients, who comprise S*troke Group 1*, who had sustained a single unilateral stroke (as assessed by patient records), were recruited from St. John's Rehabilitation Centre (see Table 2.1). All participants were right-handed, fell between the ages of 51 and 83 ($M = 72.4$, $SD = 9.3$), were fluent in English, had no known history of neurological disorders other than stroke, and were judged to be sufficiently emotionally and medically stable to participate in testing (see Appendix A for pre-screen questionnaire). To ensure that patients were able to understand experimental instructions, a minimum score of 7/10 was required on both the Spontaneous Speech and the Comprehension subtests of the Western Aphasia Battery (WAB; Kertesz, 1982).

Given that it would be necessary for participants to physically enact both NAs and NNAs, all participants were assessed on an empirically validated apraxia screening measure (Almeida, Black, & Roy, 2002) where they were required to pantomime five transitive (tool-based; e.g., show me how to brush your teeth with a toothbrush) and five intransitive (communication-based; e.g., show me how to blow out a candle) gestures and perform delayed imitation of an additional five transitive and five intransitive gestures without error. No participants met criteria for apraxia.

A familiarity questionnaire (see Appendix B) was administered to each participant prior to the first demonstration of each task in order to determine whether participants had any prior knowledge of the NNAs used in this study. Participants were excluded from the study if: (a) a NNA had been performed more than 2 times in the past year or for a total of more than 5 times in the past; or (b) if a NA had been performed fewer than 5 times in the past year or had been performed fewer than a total of 20 times in the past. Participants were excluded if they were not familiar with more than one NA or if they were familiar with more than one NNA (if only one NA or NNA was deemed to be unfamiliar or novel to a participant, respectively, it was substituted with a comparable action). No participants were excluded from the study; however, in the case of one participant (MI), one NNA (i.e., building a mock volcano) had to be replaced by a different NNA (i.e., building a compass) due to familiarity. The general purpose and procedures of the study were explained, and written and informed consent was obtained.

Age-matched controls. Sixteen healthy older adults similar in age and years of education to the stroke participants were recruited from the Waterloo Research in Aging Participant Pool (WRAP) as well as through flyers posted in the Montreal community and by word-of- mouth (see Table 2.1). Participants fell between the ages of 63 and 85 (M = 73.8, SD = 7.5) and scored in the normal range on the Modified Mini Mental Status Examination (3-MS; Bravo & Hebert, 1997), a general test of cognitive functioning (M = 96.1, SD = 3.6). Control participants were excluded if they reported any history of stroke, cardiovascular disease, hypertension (not controlled by medication), diabetes, neurological disorders, seizures, encephalitis, meningitis, thyroid disease, brain surgery, chemotherapy for cancer, sleep disorder, serious head injury, current or previous drug or alcohol abuse, medication use that can significantly affect cognition, or mood or anxiety disorder that was being treated by medication at the time of testing. All other inclusion and exclusion criteria were similar to stroke participants including handedness and English proficiency. As with the stroke group, a familiarity questionnaire was administered in order to determine whether subjects had any prior knowledge of the NNAs used in this study and to assess familiarity of routine tasks.

Table 2.1 summarizes characteristics of both stroke and age-matched control participants. A one-way analysis of variance (ANOVA) with the variables of age, education and the between-subjects factor of group (controls, stroke) showed no significant differences between groups on age and education. An independent t-test confirmed that controls had significantly higher scores ($M = 96.1$, $SD = 3.6$) on the 3-MS than participants with stroke ($M = 76.3$, $SD = 20.2$), $t(30) = 3.9$, $p = .001$.

Materials.

Naturalistic action tests. The NAs used in this study consisted of preparing: coffee using a drip filter machine, a sandwich, and a card to be mailed. The mean number of actions necessary to construct a NA was 15.7 ($SD = 4.5$) crux actions and 45.0 ($SD = 9.5$) noncrux actions. Each NA had a mean number of 6.0 ($SD = 1.0$) target objects presented as well as 3.3 ($SD = 0.6$) distractor items that were either functionally similar (e.g., coffee beans instead of coffee grounds) or physically similar (e.g., small black square stickers instead of stamps). The crux and noncrux actions for each NA are listed in Appendix C.

The following four NNAs were constructed by each participant: birdfeeder, door hanger, ear guitar, and mock volcano. The birdfeeder NNA involved constructing a birdfeeder by gluing birdseed to a styrofoam ball attached to a skewer. The door hanger NNA involved making a hanging sign out of popsicle sticks and glue. The ear guitar NNA was made by connecting two styrofoam cups by a string, where a sound could be produced when the string was pulled. The mock volcano NNA was constructed by mixing hydrogen peroxide and yeast into a bottle with an inverted cone. The two ingredients combined to produce foam which cascaded over the cone to simulate the effect of a volcano erupting. On average, the number of scripted actions necessary to complete each task was 18.5 ($SD = 9.40$) crux actions and 68.25 ($SD = 26.74$) noncrux actions. The crux and noncrux actions for each NNA as well as photo descriptions of each of the four novel tasks are included in Appendix C. NNAs had a mean number of 8.75 (*SD* = 0.5) target objects and 4.75 (*SD* = 0.5) distractor items that were either functionally similar (e.g., stapler instead of tape) or physically similar (e.g., bottled water instead of hydrogen peroxide).

Protocol development. Participant performance was measured using a modified version of the Action Coding System (ACS; Schwartz et al., 1991) where actions are classified as one of four potential behaviours: (a) TAKE, which refers to the action of reaching out and taking possession of an object to be used in completing the NA or NNA, (b) MOVE, which involves moving an object from one place to another, (c) ALTER, which refers to the act of transforming an object from one state to another (e.g., changing the state of a container of baking soda from full to empty by spooning out the baking soda), and (d) GIVE, which refers to the relinquishing of an object.

Primary actions are grouped together to form a subgoal. The primary actions for each NA and NNA are summarized in Appendix C. Each action is associated with a particular subgoal, and each subgoal must have at least one crux action. Crux actions are defined as one of the central actions within a particular naturalistic action. For example, spooning coffee grounds into a filter is one of the central actions involved in making a cup of coffee. Noncrux actions are not central actions but they enable the crux action (e.g., opening the can of coffee grounds) or are performed after a central action as 'housekeeping' (e.g., closing the can of coffee). Crux and noncrux actions for each NNA and NA script were determined by three independent raters who viewed each videotape several times in order to identify the crux and noncrux actions enacted on the videotape.

Any discrepancies between raters were resolved through discussion of the three raters after the review of the videotape. Appendix D summarizes the list of crux and non-crux actions associated with each NA and NNA.

Scoring and performance measures.

Scoring error. Errors were categorized as either an error of commission or as an error of omission. A *commission error* includes any action that was attempted but executed incorrectly. For example, the subject fills the coffee filter, but does so with coffee beans instead of coffee grounds. *Errors of omission* represent actions present in the scoring protocol that were not attempted.

Measures of performance. An accomplishment score was calculated by counting the total number of actions that were correctly executed out of the total actions for that task listed in the modified ACS protocol, multiplied by 100. Omission error rate was derived by taking the number of actions that were never enacted out of the total number of actions listed within the NNA or NA scoring protocol, multiplied by 100. Finally, the commission error rate was determined by taking the number of actions that were executed erroneously out of the total number of possible within the NNA or NA multiplied by 100. All three scores were calculated separately for both crux and noncrux actions. Rate scores were calculated so that crux and noncrux action performance could be compared.

Inter-rater reliability was determined by having a second rater independently score 30% of the data. Analyses were conducted on the primary independent measures using a two-way mixed-model intraclass correlation coefficient (ICC; Shrout & Fleiss, 1979). An ICC has been shown to be equivalent to a weighted kappa and is recommended in analyses with several nominal variables to be judged that behave more like ordinal variables (Fleiss & Cohen, 1973). High inter-rater reliability was achieved for all measures, based on an ICC cut-off of 0.7, which is considered acceptable in psychological research (Landis & Koch, 1977). Specifically, the ICC for the crux accomplishment score was 0.8, $F(31, 31) = 7.3, p < .001$ and for the noncrux accomplishment score, it was 0.8, $F(31, 31) = 6.9, p < .001$. The ICC for the crux omission rate, was 0.8, $F(31, 31) = 10.6, p < .001$, and for the noncrux omission rate it was 0.8, $F(31, 31) = 10.3, p < .001$. Finally, the crux commission rate was 0.9, $F(31, 31) = 13.0, p < .001$, and the noncrux commission rate was 0.7, $F(31, 31) = 5.5, p < .001$.

Design.

The current study used a mixed experimental design. Participants from both groups (i.e., stroke, age-matched controls) were required to enact the construction of four NNAs over three learning trials and three NAs, one time each. The order of presentation of NAs and NNAs, as well as individual tasks within each block of NAs and NNAs were counterbalanced across participants (see Appendix E).

Procedure.

Enactment. Each NNA was physically performed by a demonstrator and subsequently enacted by the participant. Participants were told to watch carefully as a task was being demonstrated because they would be asked to perform the task exactly as it had been demonstrated. Following a 90-second delay, participants attempted to construct the NNA they had just viewed. The materials and their position was the same as during the demonstration. This procedure was repeated for a total of three times. In the event that one NNA was known to a participant, another NNA, Compass, was substituted in its place (only one participant had Volcano replaced by Compass due to familiarity). The tester provided assistance only when the subject's intended action was clearly stated or could be easily inferred. For example, some participants with hemiparesis were unable to perform actions that required both hands (e.g., opening a jar of mustard). As such, the tester would open the jar if the participant indicated that they needed help doing so. Participants were tested individually in a quiet testing room. Testing was divided into several one-hour sessions. Participants' enactments were videotaped for later scoring and evaluation. The control group enacted each NNA only once because it was anticipated that their performance would be close to ceiling after one trial.

Participants performed each of the three NAs without a prior demonstration. They were instructed to use the materials in front of them to make a cup of coffee, prepare a card to be mailed, and put together a sandwich.

Standardized psychological tests. In addition to experimental measures, participants with stroke also completed a battery of neuropsychological tests. These tests included measures of mental status, language, executive function, and memory (see Appendix F). Stroke participant performance on individual neuropsychological tests comprising each of the following three measures is listed in Appendix G.

Episodic memory composite. To increase measurement reliability, composite measures of neuropsychological test performance were developed by combining test measures of the same cognitive domain. The episodic memory composite was derived by averaging total and delayed recall z-scores of the Hopkins Verbal Learning Test - Revised (HVLT-R) and Brief Visuospatial Memory Test - Revised (BVMT-R). Normative z-scores for each test measure were obtained from test administration manuals.

Executive function composite. The executive function composite measure was derived by averaging the z-scores of the following measures of executive function: Trail Making Test part B completion time, Stroop ratio of interference score (time to state color of words printed in different color ink/ time to state color of colored dots), Clock Drawing test total score, and the phonemic fluency score (total number of words correctly generated across three trials with letter cues F, A, and S).

BVMT –R item and association scores. The BVMT-R Item and Association scores were determined using the scoring procedure described by Troyer et al. (2008). Item scores were determined by awarding a point for each recognizable object recalled. Credit for an association was given if a recognizable object was recalled in the correct location. The present study used the corrected association score, calculated by dividing the number of recognizable objects accurately located by the number of recognizable objects. Thus, the corrected associative recall score, averaged across the three learning trials, falls within the range of zero and one. Troyer et al. (2008) found similar patterns between the uncorrected and corrected associative score and as such, the corrected associative score will be used in this study. Item and association scores were calculated by averaging performance across the three learning trials.

Approach to Data Analyses. Participant enactment performance was scored and analyzed for both NAs and NNAs. For all statistical analyses, the alpha level was set at .05, with all multiple comparisons adjusted with a Bonferroni correction. Enactment performance was assessed by two distinct measures. One measure, accomplishment performance, provides an overall assessment of performance, but it is less precise than the second measure, an analysis of omission and commission error rates. The present study relied on omission and commission error rates in analyzing the relationship between neuropsychological test scores and enactment performance, and in the analysis of the relationship between enactment performance and brain lesions. Accomplishment was used to assess overall performance only. Previous studies with NNAs (Gold & Park, 2009; Park et al., 2012) and NAs (e.g., Giovannetti et al., 2002; Schwartz et al., 1999; Buxbaum et al., 1998) used this approach. The relationship between NA and NNA omission and commission error rates and participant performance on neuropsychological test measures was investigated using bivariate correlations and hierarchical linear regressions.

Results

Enactment performance.

NNA Trial 1 enactment performance.

NNA accomplishment performance at Trial 1. An initial analysis determined whether age-matched controls differed from participants with stroke in NNA Trial 1 accomplishment performance (see Figure 2.1). A repeated measures ANOVA with within-subjects factor of action type (crux, noncrux) and a between-subjects factor of group (controls, stroke) demonstrated a significant effect of group, $F(1, 30) = 8.64$, $p = .006$, $\eta_p^2 = .224$, where control participants accomplished a greater proportion of actions overall. In addition, there was a significant two-way interaction between action type and group, $F(1, 30) = 18.35$, $p < .000$, $\eta_p^2 = .380$. Post-hoc independent t-tests confirmed that controls accomplished more noncrux actions ($M = 84.90$, $SD = 11.22$) than participants with stroke, ($M = 66.02$, $SD = 15.84$), $t(30) = 2.02$, $p = .001$, $\eta_p^2 = .120$. In contrast, there was no significant difference in NNA Trial 1 accomplishment crux performance between groups in Trial 1. There was also a significant effect of action type, $F(1, 30) = 12.90$, $p = .001$, $\eta_p^2 = .301$, where crux accomplishment scores tended to be higher than noncrux accomplishment performance. In summary, individuals with stroke accomplished significantly fewer actions than age-matched controls. Further analyses showed that participants with stroke accomplished fewer noncrux actions than controls. There was no difference in the proportion of crux actions correctly performed between the two groups.

NNA error analysis of Trial 1. NNA Trial 1 error production was analyzed in order to determine whether there were any group differences in patterns of error production (see Figure 2.2). A repeated measures ANOVA with the within-subjects factors of error type (omission, commission) and action type (crux, noncrux) and the between-subjects variable of group obtained a significant main effect of group, $F(1, 30) = 7.76$, $p = .009$, $\eta_p^2 = .205$, where participants with stroke made more errors overall than age-matched controls. A significant two-way interaction between action type (crux, noncrux) and group (controls, stroke) was observed, $F(1, 30) = 7.60$, $p = .010$, $\eta_p^2 = .202$, where participants with stroke made more noncrux ($M = 18.78$, $SD = 8.52$) than crux errors, (M = 15.46, SD = 10.71), $t(15) = -2.79$, $p = .014$, $\eta_p^2 = .342$. There was no significant difference between crux and noncrux errors in controls. In addition, a two-way interaction between error type and action type was observed, $F(1, 30) = 22.95$, $p < .001$, $\eta_p^2 = .433$. Follow-up t-tests indicated that participants made significantly more noncrux (M = 18.42, SD = 13.66) than crux (M = 13.06, SD = 11.52) omission errors, $t(31) = -5.83$, $p < .001$, $\eta_p^2 = .523$. There was no difference between the rate of crux and noncrux commission errors. Other effects included a significant effect of action type, $F(1, 30) = 4.50$, $p = .042$, $\eta_p^2 = .130$, reflecting higher noncrux than crux errors rates, as well as a main effect of error type, $F(1, 30) = 9.90$, $p = .004$, $\eta_p^2 = .248$, where participants demonstrated higher rates of omission than commission errors.

Taken together, participants with stroke made more noncrux errors than controls in NNA T1. Subsequent analyses showed that stroke participants tended to make more noncrux than crux errors whereas, controls showed no difference in the types of actions performed. Further, all participants made significantly more noncrux than crux omission errors, but there was no difference between crux and noncrux commission error rates. A greater proportion of noncrux than crux errors was performed by participants. Also, greater omission than commission error rates were also observed.

NNA performance across three learning trials in participants with stroke.

NNA accomplishment performance. NNA crux and noncrux accomplishment performance was analyzed in order to determine whether performance improved across three learning trials in participants with stroke (see Figure 2.1). A repeated measures ANOVA with within-subjects factors of trial (T1, T2, T3) and action type (crux, noncrux) obtained a significant main effect of trial, $F(1, 30) = 32.76$, $p < .000$, $\eta_p^2 = .686$. In addition, a two-way interaction of action type (crux, noncrux) by trial was found, $F(2, 15) = 7.32$, $p = .003$, $\eta_p^2 = .328$. Follow-up post hoc analyses showed that a higher percentage of crux ($M = 73.25$, $SD = 18.11$) than noncrux actions ($M = 66.02$, $SD = 15.84$) were performed in Trial 1, $t(15) = 4.87$, $p < .000$, $\eta_p^2 = .613$. Similarly, more accomplishment crux ($M = 87.32$, $SD = 15.27$) than noncrux actions ($M = 83.08$, $SD = 10.59$) were performed in Trial 3, $t(15) = 2.42$, $p = .029$, $\eta_p^2 = .281$. In contrast, accomplishment performance for crux and noncrux actions was comparable in Trial 2. Other effects included a significant effect of action type, $F(1, 30) = 9.44$, $p = .008$, $\eta_p^2 = .386$, where participants with stroke tended to perform a significantly higher proportion of crux than noncrux actions. In summary, performance improved across trials for both crux and noncrux actions. More crux than noncrux actions were performed in trials 1 and 3, although performance was comparable between the two action types in Trial 2.

NNA error analysis. Patterns of error performance across the trials were examined for participants with stroke (Figure 2.2). A repeated measures, within-subjects ANOVA with factors trial (T1, T2, T3), error type (omission, commission), and action type (crux, noncrux) found a significant three-way interaction between trial (T1, T2, T3), error type (omission, commission), and action type (crux, noncrux), $F(2, 14) = 4.29$, $p = .035$, $\eta_p^2 = .380$. Follow-up ANOVAs were conducted to explore this interaction for crux and noncrux actions separately with the factors of trial (T1, T2, T3) and error type (omission, commission). For crux actions (See Figure 2.2a), there was a significant main effect of trial, where the proportion of crux errors decreased across trials, $F(2,30) = 9.965$, $p <$

.000, $\eta_p^2 = .399$. Post-hoc t-tests confirmed that the overall crux error rate in Trial 3 (M = 8.50, SD = 10.11) was significantly lower than the proportion of crux errors in Trial 2 (M = 12.11, SD = 9.93), $t(15) = 2.84$, $p = .012$, $\eta_p^2 = .350$, as well as lower than crux error rates in Trial 1 (M = 15.46, SD = 10.71), $t(15) = 3.52$, $p = .003$, $\eta_p^2 = .453$. Further, a significant main effect of error type was demonstrated, $F(1,15) = 6.25$, $p = .025$, η_p^2 = .294, where a higher rate of commission than omission type errors were produced.

For noncrux actions (see Figure 2.2b), an effect of trial was demonstrated, where total noncrux error rates decreased across trials, $F(2, 30) = 35.39$, $p < .000$, $\eta_p^2 = .702$. Further analysis confirmed that noncrux error rates in Trial 3 (M = 9.98, SD = 6.73) were significantly lower than noncrux error rates in Trial 2 (M = 12.11, SD = 7.60), $t(15)$ = 2.82, $p = .013$, $\eta_p^2 = .429$, as well as lower than error rates in Trial 1 (M = 18.78, SD = 8.52), $t(15) = 6.23$, $p < .000$, $\eta_p^2 = .721$. Further, a significant main effect of error type was demonstrated, $F(1,15) = 25.246$, $p < .000$, $\eta_p^2 = .627$, where participants produced more omission than commission errors on noncrux actions.

Overall, these findings showed that the proportion of crux and noncrux omission and commission errors decreased across learning trials. In addition, a different error pattern for crux and noncrux actions was observed. As hypothesized, for crux actions, participants with stroke tended to make more commission than omission errors. In contrast, for noncrux actions, participants made more omission than commission errors.

The relationship between NNA enactment and neuropsychological test performance.

NNA error production across trials in relation to neuropsychological test

performance. A Pearson correlational analysis was conducted to further investigate the relationship between NNA omission and commission error rates and stroke participant performance on neuropsychological test measures. Table 2.2 presents the correlation coefficients between omission and commission error rates of stroke participants on episodic memory, executive function, and associative memory measures across the three learning trials. As shown in Table 2.2, negative correlation coefficients were obtained, indicating that higher scores on neuropsychological test measures were associated with lower error rates. In the case of participant performance on measures of executive function, higher omission crux error rates were shown to be consistently associated with lower executive function scores across all three trials. Further, although Trial 1 omission noncrux error rates were associated with lower executive function scores, the strength of this relationship diminished by T2. In contrast, commission crux and noncrux error rates were not significantly correlated with executive function measures.

With regard to episodic memory, higher omission crux errors were strongly correlated with lower scores on measures of episodic memory, especially in T1 and T2. The relationship between lower episodic memory composite scores and higher omission noncrux error rates was also observed across all three trials, although the association was stronger in T1 than in T2 and T3. Higher commission crux and noncrux error rates were found to be associated with lower episodic memory scores for T2 only.

The relationship between NNA omission and commission error rates and a measure of associative memory was further investigated. Both higher omission crux and noncrux errors were shown to be strongly related to lower associative memory scores for all three trials. In addition, higher commission crux errors were strongly associated with lower BVMT associative memory in T2 and T3.

Hierarchical regression was used to assess the relative contribution of associative memory in comparison to episodic memory and executive function in the prediction of crux and noncrux omission and commission error rates. Associative memory was included in Block 1 and episodic memory and executive function were entered together in Block 2. This analysis was carried out for T1 and T3 separately for omission and commission crux and noncrux errors.

For NNA T1 crux omission errors, Model 1 showed that associative memory significantly predicts 64.9% of the variability in NNA crux omission error rates, $F(1, 10) = 18.50, p = .002$ (Table 2.3). Model 2 accounted for an increase of 9.1% of the variability in NNA omission crux error rates accounted for, which was not significant. Thus, neither the episodic memory nor executive function composites were demonstrated to be significant predictors of NNA crux omission error rates. Similar findings were obtained for NNA T1 noncrux omission error rates. Model 1 showed that associative memory significantly predicts 65.0% of the variability, $F(1, 10) = 18.56, p = .002$ (Table 2.4). Model 2 accounted for an increase of 9.1% of the variability in NNA omission noncrux error rates accounted for, which was not significant. Thus, neither the episodic memory nor executive function composites were significant predictors of NNA crux and noncrux omission error rates.

For commission errors in NNA T1, neither Model 1 nor Model 2 were shown to be significant; thus, indicating that neither associative memory nor all three independent variables together (associative memory, episodic memory, and executive function) were significant predictors of NNA T1 crux (Table 2.5) and noncrux (Table 2.6) commission error rates. Further, the pattern of results for T1 was generally replicated with analogous analyses performed with T3 (see Appendix H). These results should be interpreted with caution given the small sample size.

Comparing NA and NNA performance.

NA performance.

NA accomplishment performance. Prior to investigating the relationship between NA and NNA performance, NA performance was analyzed (see Figure 2.3). A repeated measures ANOVA with a within-subjects factor of action type and a between-subjects factor of group (stroke, controls) obtained a significant effect of group, $F(1, 28) = 30.10$, $p < .000$, $\eta_p^2 = .518$, where controls accomplished more actions than participants with stroke. In addition, a significant main effect of action type was observed, $F(1, 28) = 8.31$, $p = .007$, $\eta_p^2 = .229$, indicating that participants accomplished more crux than noncrux actions.

NA error analysis. NA error rates were examined across the two participant groups (see Figure 2.4). A repeated measures ANOVA with within-subjects factors of error type (omission, commission) and action type (crux, noncrux) and a between-subjects factor of group (stroke, controls) obtained a significant effect of group, $F(1, 28) = 30.79$, $p < .000$, $\eta_p^2 = .524$, where participants with stroke made a greater proportion of errors overall ($M = 25.15$, $SD = 12.26$) than did controls ($M = 6.21$, $SD = 3.91$).

In addition, a significant three-way interaction between error type, action type, and group, $F(1, 28) = 12.82$, $p = .001$, $\eta_p^2 = .314$ was demonstrated. The three-way interaction was investigated separately for each group. For participants with stroke, a two-way interaction was shown between error type and action type, $F(1, 13) = 11.84$, $p = .001$, $\eta_p^2 = .314$. Separate paired-sample t-tests compared omission and commission errors for each error type. For omissions, no significant difference was obtained between the proportion of crux and noncrux errors produced. In contrast, for commission errors, participants with stroke made more noncrux ($M = 17.39$, $SD = 8.12$) than crux ($M = 8.99$, $SD = 10.83$) errors, $t(13) = -3.76$, $p = .002$, $\eta_p^2 = .521$. A significant main effect of error was observed $F(1, 13) = 17.42$, $p = .001$, $\eta_p^2 = .573$, where participants made more omission than commission errors overall. Further, a significant main effect of action type was also obtained, $F(1, 13) = 6.38$, $p = .025$, $\eta_p^2 = .329$ where more errors were made on noncrux than crux actions.

For age-matched controls, there was no significant interaction shown between error type and action type. However, a significant main effect of error type was obtained, $F(1, 15) = 18.05$, $p = .001$, $\eta_p^2 = .546$, which demonstrated that participants made more omission than commission type errors overall. A main effect of action type was also observed, $F(1, 15) = 10.88$, $p = .005$, $\eta_p^2 = .420$, where controls made more noncrux than crux errors.

Taken together, participants with stroke made more errors overall when compared to age-matched controls. Further, for commission errors, they made a greater proportion of noncrux than crux errors; however, there was no difference between the proportion of crux and noncrux errors omitted. Participants with stroke made more omission than commission errors overall. For controls, there was no interaction between error type and action type, but they made more omission than commission type errors.

Comparison of NA and NNA performance on T1.

Accomplishment performance. Participant NA and NNA T1 accomplishment performance patterns were analyzed for both participants with stroke and age-matched controls (see Figure 2.3). A repeated measures ANOVA with within-subjects factors of familiarity (NA, NNA) and action type (crux, noncrux) and between-subjects factor of group (stroke, controls) obtained a significant effect of group, $F(1, 28) = 20.69, p < .000$, $\eta_p^2 = .425$, where controls accomplished more actions overall than participants with stroke.

There was a significant three-way interaction between familiarity, action type and group, $F(1, 28) = 7.96, p = .009, \eta_p^2 = .221$. The three-way interaction was investigated separately for each group. For participants with stroke, the interaction between familiarity and action type was not shown to be significant. A significant main effect of familiarity was observed, $F(1, 13) = 10.33, p = .007, \eta_p^2 = .443$, where stroke participants performed better on NNAs than NAs. Further, a main effect of action type was also obtained, $F(1, 13) = 21.49, p < .000, \eta_p^2 = .623$, which demonstrated that participants accomplished more crux than noncrux actions overall.

In contrast, for controls, a two-way interaction was obtained between familiarity and action type, $F(1, 15) = 8.69, p = .010, \eta_p^2 = .367$. Follow-up t-tests showed that for crux actions, participants accomplished more NA ($M = 90.63$, $SD = 8.84$) than NNA ($M =$

84.27, SD = 12.26) crux actions, $t(15) = 2.83$, $p = .013$, $\eta_p^2 = .348$. There was no significant difference between NA and NNA noncrux accomplishment. In addition, a significant main effect of familiarity was also demonstrated, $F(1, 15) = 5.13$, $p = .039$, $\eta_p^2 = .255$, where controls performed better on NAs than NNA Trial 1. There was no significant difference found between the proportion of crux and noncrux actions accomplished.

In summary, as expected, controls performed better on NAs and NNAs. Unexpectedly, however, stroke participants showed better performance on NNA T1 than NA enactment, whereas controls performed better overall on NAs compared to NNAs.

Error analysis. An initial analysis determined whether patterns of NA versus NNA T1 performance in controls differed from that of participants with stroke (see Figure 2.4). A repeated measures ANOVA with within-subjects factors of familiarity (NA, NNA), error type (omission, commission), and action type (crux, noncrux) and a between-subjects factor of group (controls, stroke) obtained a significant main effect of group, $F(1, 28) = 20.29$, $p < .000$, $\eta_p^2 = .420$. Post-hoc t-tests confirmed that for NAs, participants with stroke made significantly more omissions overall (M = 33.64, SD = 19.10) than age-matched controls (M = 9.07, SD = 6.53), $t(28) = -4.84$, $p < .000$, $\eta_p^2 = .456$. Similarly, participants with stroke made more NA commission errors overall (M = 16.67, SD = 10.13) than controls (M = 3.36, SD = 2.05) $t(28) = -5.15$, $p < .000$, $\eta_p^2 = .486$. Comparable patterns of error production were found for NNAs. Specifically, stroke participants made more NNA omissions overall (M = 22.90, SD = 14.21) than controls (M = 11.74, SD = 9.21), $t(30) = -2.64$, $p = .013$, $\eta_p^2 = .188$ and more NNA commission errors overall ($M = 15.73$, $SD = 7.47$) than age-matched controls ($M = 5.91$, $SD = 7.18$), $t(30) = -3.79$, $p = .001$, $\eta_p^2 = .324$.

In addition, a significant four-way interaction was obtained between familiarity, error type, action type, and group, $F(1, 28) = 10.13$, $p = .004$, $\eta_p^2 = .266$. This four-way interaction was further investigated separately for crux and noncrux actions. For crux actions, a repeated measures ANOVA with familiarity (NA, NNA), error type (omission, commission) as within-subjects factors and group (stroke, controls) as a between-subjects factor showed that there was a significant interaction between familiarity, error type, and group, $F(1, 28) = 12.29$, $p = .002$, $\eta_p^2 = .305$. To further understand this interaction, error types were analyzed separately for NAs and NNAs (see Figure 2.4a). Examination of NA performance for participants with stroke and controls through an ANOVA with error type as the within-subjects factor and group revealed a significant two-way interaction between error type and group, $F(1, 28) = 13.86$, $p = .001$, $\eta_p^2 = .331$, where participants with stroke make more omission ($M = 34.40$, $SD = 21.43$) than commission ($M = 8.99$, $SD = 10.83$) type errors, $t(13) = 4.60$, $p = .001$, $\eta_p^2 = .619$. Similarly, controls made more omission ($M = 34.40$, $SD = 21.43$) than commission ($M = 8.99$, $SD = 10.83$) type errors, $t(15) = 4.73$, $p < .000$, $\eta_p^2 = .599$, but stroke participants show an overall higher proportion of omission to commission errors relative to controls. A significant main effect of error type was also observed, $F(1, 28) = 34.13$, $p < .000$, $\eta_p^2 = .549$, where more omission than commission errors were performed overall. For NNAs, a repeated measures ANOVA with a within-subjects factor of error type and a between-subjects factor of group indicated that unlike with NAs, there was no significant effect of error type and error type did not interact with group.

For noncrux actions, a repeated measures ANOVA with familiarity (NA, NNA), error type (omission, commission) as within-subjects factors and group (stroke, controls) as a between-subjects factor showed that there was a significant two-way interaction between familiarity and group, $F(1, 28) = 17.44$, $p < .000$, $\eta_p^2 = .384$, where participants with stroke made significantly more omission and commission noncrux errors in NAs ($M = 25.41$, $SD = 11.21$) than NNAs ($M = 17.70$, $SD = 8.47$), $t(13) = 3.68$, $p = .003$, $\eta_p^2 = .510$ (see Figure 2.4b). There was no difference between NA and NNA error performance for control subjects. A significant main effect of error type was observed, $F(1, 28) = 27.75$, $p < .000$, $\eta_p^2 = .498$, where participants tended to make more omission than commission type errors.

Thus, as with accomplishment performance, participants with stroke performed less well on NAs than NNAs. In addition, participants with stroke made more omission and commission errors overall than controls for both NAs and NNAs. For crux actions, both participants with stroke and controls made more omission than commission errors when performing NAs. In contrast, there was no difference between omission and commission crux error production in NNAs. In the case of noncrux actions, stroke participants made more errors when performing NAs than NNA, whereas there was no difference in NA and NNA noncrux error production in age-matched controls. A greater proportion of omission than commission noncrux errors were performed overall.

Comparison between NA and NNA T1 error production and neuropsychological test measures in stroke participants.

Correlations between outcome measures and neuropsychological test measures.

The Pearson correlation coefficients between NA error production and performance on the neuropsychological test battery for participants with stroke are shown in Table 2.7. For NAs, higher omission crux and noncrux error rates were shown to be significantly correlated with lower scores on the executive function and episodic memory composite measures. Higher omission noncrux error rates were also found to be associated with lower associative memory. NA commission error rates were not found to be significantly related to either executive function and episodic memory composite measures nor associative memory scores.

Taken together with correlational analyses looking at NNA T1 error rates and neuropsychological test scores, better performance on episodic memory measures was correlated with fewer errors produced for both NAs and NNAs. Similar patterns were demonstrated with executive function, although the relationship between higher executive function composite scores and a smaller proportion of errors produced was stronger in NAs than NNAs. NA and NNA commission error rates were not shown to be significantly related to neuropsychological test measures.

Comparison of regression analyses of NA and NNA error rates on neuropsychological test measures. The correlations between NA behavioral measures and neuropsychological test scores were further investigated by doing a hierarchical regression. The approach used was analogous to the one described above for NNAs. Summaries of NA regression models are shown in Tables 2.8-2.11.

Taken together, associative memory, episodic memory, and executive function (Model 2) significantly account for 79.0% of the variability in NA crux omission error rate, $F(3, 8) = 10.05$, $p = .004$ (See Table 2.8). Further, it was determined that the episodic memory composite variable uniquely predicts 24.2 % of the variability of NA omission crux error rate, $t = -3.04$, $p = .016$. Associative memory and executive function composite scores were not found to be significant predictors for this type of error.

Similar results were obtained for NA noncrux omission error rates. Model 2 significantly accounts for 80.1% of the variability in NA noncrux omission error rate, $F(3, 8) = 10.75$, $p = .004$ (See Table 2.9). The episodic memory composite variable uniquely predicts 12.8 % of the variability of NA omission noncrux error rate, $t = -2.27$, $p = .05$. No other independent variables were found to be significant predictors for this type of error.

With regard to commission errors, neither Model 1 nor Model 2 were found to be significant; thus, indicating that neither associative memory nor all three independent variables together (associative memory, episodic memory, and executive function) were found to be significant predictors of NA crux (Table 2.10) and noncrux (Table 2.11) commissions.

In summary, these results further illustrate how NAs and NNA may involve overlapping, but also unique cognitive processes. With NNAs, associative memory was the only significant predictor of both NNA omission crux and noncrux error rates. In contrast, for NAs, episodic memory was the only significant predictor of both NA crux and noncrux omission error rates. Commission error rates were not shown to be predicted by associative memory, nor the episodic memory and executive function composites for either NAs or NNAs.

Table 2.1

Participant Characteristics

	Number (N)	Mean Age (SD)	Education (Years) (SD)	3-MS (SD)
Age-matched controls	16	73.8 (7.5)	11.3 (4.0)	96.1 (3.6)
Participants with Stroke	16	72.4 (9.3)	10.9 (5.6)	76.3 (20.2)

Note. 3-MS = Modified Mini Mental State Examination, Bravo & Hebert, 1997.

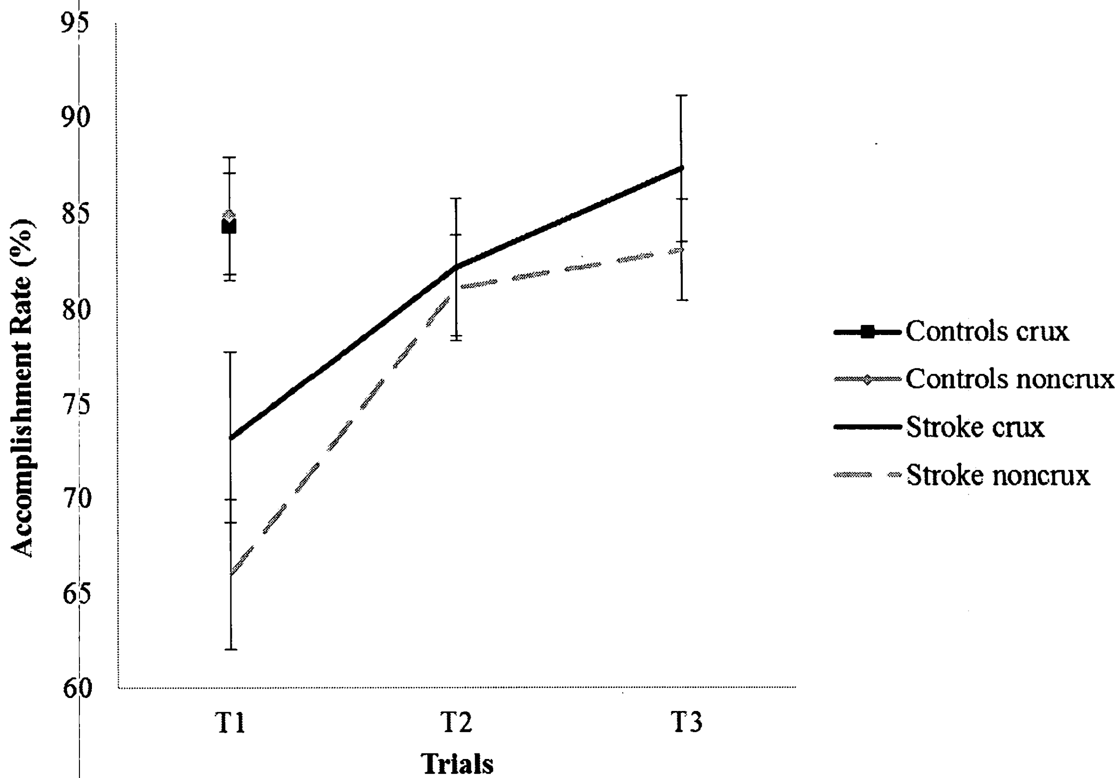
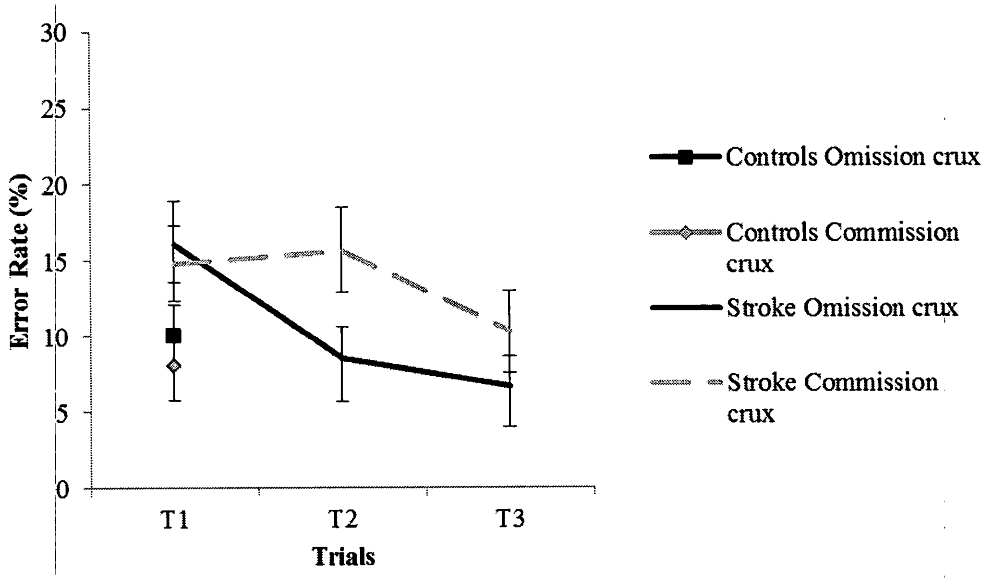


Figure 2.1. Standard NNA Accomplishment rate (+/- SE) across Three Learning Trials

A.



B.

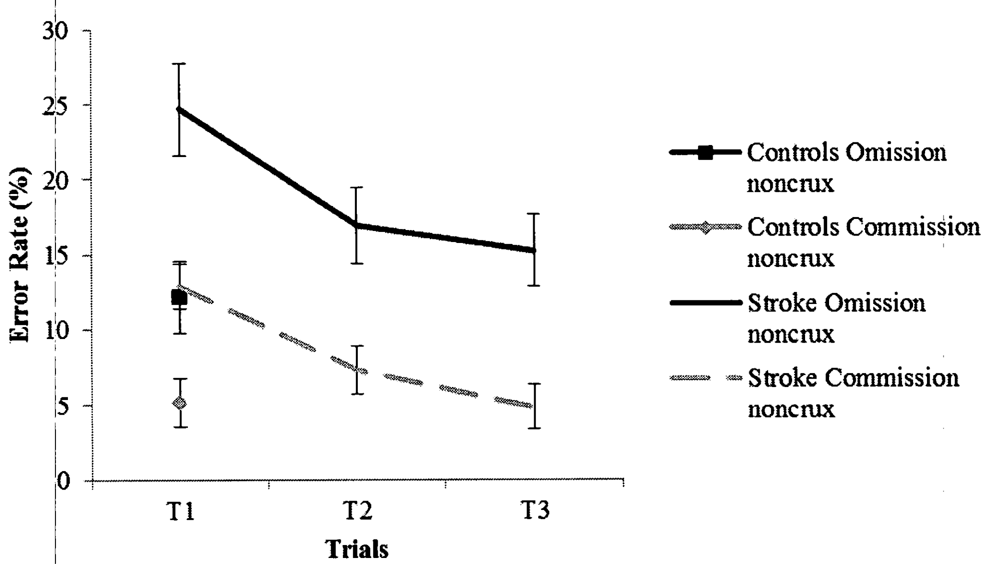


Figure 2.2. Omission and Commission Error Rates for Participants with Stroke and Controls by Learning Trial. A. Crux Error Rates (+/- SE). B. Noncrux Error Rates (+/- SE).

Table 2.2

Correlation between Neuropsychological Measures and NNA Omission and Commission Error Rates

Measure	Trial	Om. Crux	Om. noncrux	Comm. crux	Comm. noncrux
Executive Function Composite	1	-.575*	-.571*	-.162	-.272
	2	-.522*	-.351	-.465	-.475
	3	-.533*	-.396	-.355	.032
Episodic Memory Composite	1	-.697**	-.738**	-.414	-.426
	2	-.712**	-.638*	-.631*	-.669*
	3	-.597*	-.629*	-.521	-.349
BVMT-R Associative Memory	1	-.806**	-.806**	-.434	-.135
	2	-.794**	-.770**	-.772**	-.669
	3	-.791**	-.738**	-.735**	-.555

Note. Om. = Omission Error; Comm. = Commission Error; BVMT-R = Brief Visuospatial Memory Test- Revised, Benedict, 1997.
$^{*}p \leq .05$, $^{**}p \leq .01$.

Table 2.3

Summary of NNA Regression Analysis for Variables Predicting Crux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.396	.066	
Associative Memory	-.323	.075	-.806**
Model 2			
Constant	.336	.123	
Associative Memory	-.285	.109	-.711*
Episodic Memory Composite	.011	.051	-.083
Executive Function Composite	-.052	.044	-.349

$R^2 = .649$ for Model 1 ($p = .002$); R^2 change = .075 for Model 2 ($p = .381$)
* $p < .05$; ** $p < .01$

Table 2.4

Summary of NNA Regression Analysis for Variables Predicting Noncrux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.507	.072	
Associative Memory	-.353	.082	-.806**
Model 2			
constant	.391	.130	
Associative Memory	-.272	.116	-.622*
Episodic Memory Composite	-.011	.054	-.076
Executive Function Composite	-.048	.047	-.292

$R^2 = .650$ for Model 1 ($p = .002$); R^2 change = .091 for Model 2 ($p = .301$)
* $p < .05$; ** $p < .01$

Table 2.5

Summary of NNA Regression Analysis for Variables Predicting Crux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.195	.056	
Associative Memory	-.097	.064	-.434
Model 2			
Constant	.156	.117	
Associative Memory	-.069	.104	-.309
Episodic Memory Composite	-.009	.048	-.121
Executive Function Composite	-.007	.042	-.085

R^2 = .188 for Model 1 (p = .159); R^2 change = .022 for Model 2 (p = .896)

Table 2.6

Summary of NNA Regression Analysis for Variables Predicting Noncrux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.140	.045	
Associative Memory	-.022	.051	-.135
Model 2			
constant	.026	.081	
Associative Memory	.065	.072	.402
Episodic Memory Composite	-.045	.033	-.819
Executive Function Composite	.007	.029	.114

R^2 = .018 for Model 1 (p = .677); R^2 change = .255 for Model 2 (p = .301)

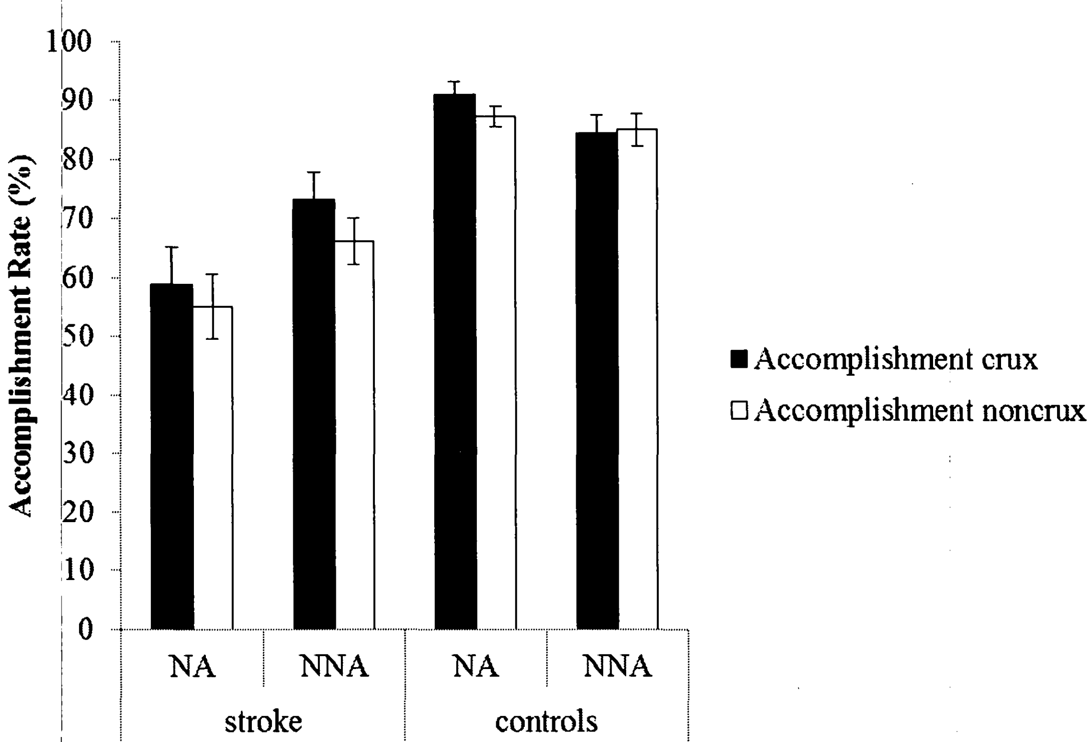
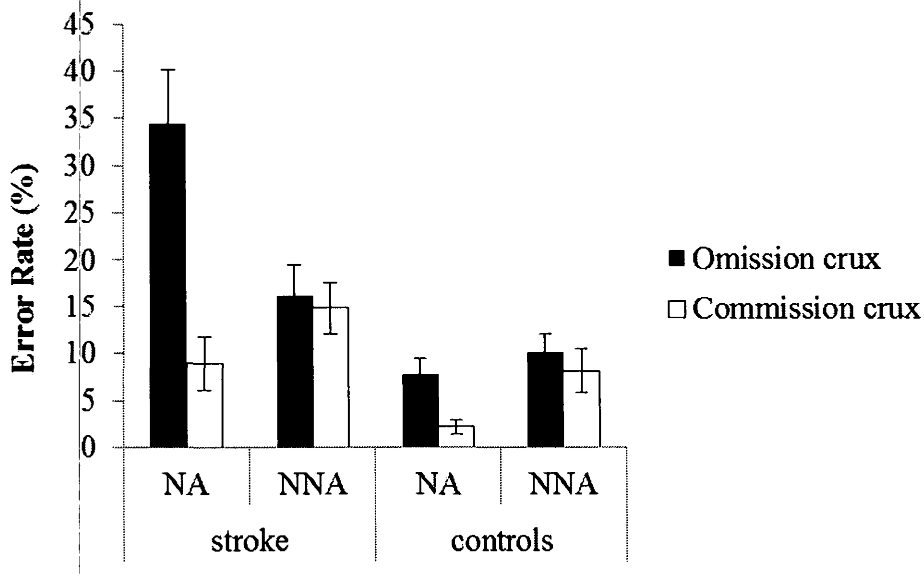


Figure 2.3. NA and NNA T1 Accomplishment Rates (+/- SE) for Participants with Stroke and Age-Matched Controls

A.



B.

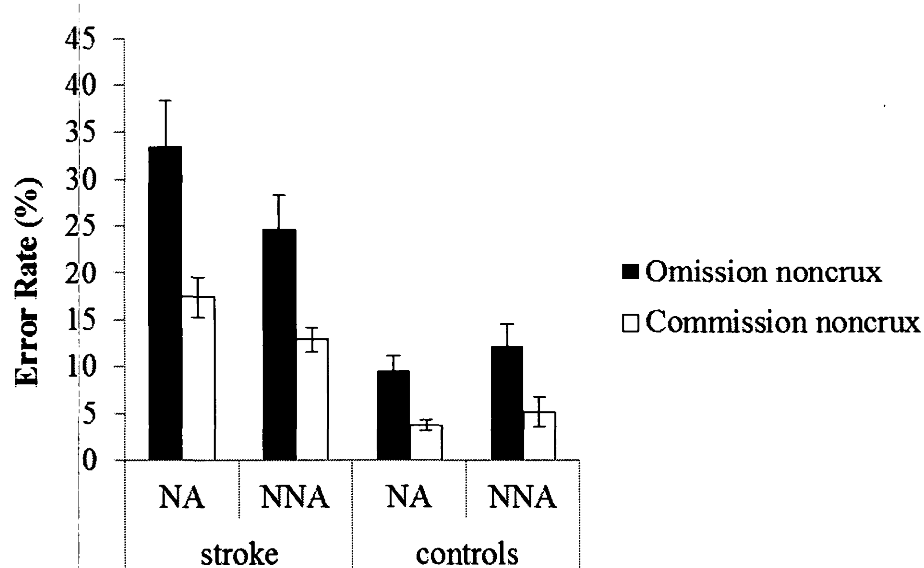


Figure 2.4. NA and NNA T1 Crux and Noncrux Error Rates of Stroke Participants and Controls. A. Omission and Commission Crux Error Rates (+/- SE). B. Omission and Commission Noncrux Error Rates (+/- SE).

Table 2.7

Comparison between NA and NNA T1 Error Production and Neuropsychological Test Measures in Stroke Participants

Measure	NA. Om. Crux	NA. Om. Noncrux.	NA.Comm. Crux	NA.Comm. Noncrux	NNA. Om. Crux	NNA. Om. Noncrux.	NNA.Comm. Crux	NNA.Comm. Noncrux
Executive Function Composite	-.690**	-.708**	-.243	-.270	-.575*	-.571*	-.162	-.272
Episodic Memory Composite	-.874**	-.883**	-.378	-.425	-.697**	-.738**	-.414	-.426
BVMT Associative Memory	-.574	-.593*	-.408	-.345	-.806**	-.806**	-.434	-.135

Note. NA = Routine Naturalistic Actions; NNA = Novel Naturalistic Actions; Om. = Omission Error; Comm. = Commission Error; BVMT = Brief Visuospatial Memory Test.

$^{*}p \leq .05$, $^{**}p \leq .01$.

Table 2.8

Summary of NA Regression Analysis for Variables Predicting Crux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.596	.153	
Associative Memory	-.339	.173	-.527
Model 2			
constant	-.026	.172	
Associative Memory	.130	.153	.202
Episodic Memory Composite	-.217	.072	-.994*
Executive Function Composite	-.009	.062	-.036

$R^2 = .278$ for Model 1 ($p = .078$); R^2 change = .513 for Model 2 ($p = .007$)
* $p < .05$

Table 2.9

Summary of NA Regression Analysis for Variables Predicting Noncrux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.607	.130	
Associative Memory	-.342	.147	-.593*
Model 2			
constant	.120	.151	
Associative Memory	.018	.134	.031
Episodic Memory Composite	-.142	.062	-.723*
Executive Function Composite	-.051	.054	-.237

$R^2 = .351$ for Model 1 ($p = .042$); R^2 change $= .450$ for Model 2 ($p = .009$)
* $p < .05$

Table 2.10

Summary of NA Regression Analysis for Variables Predicting Crux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.205	.084	
Associative Memory	-.135	.096	-.408
Model 2			
constant	.111	.172	
Associative Memory	-.062	.153	- .186
Episodic Memory Composite	-.043	.071	-.381
Executive Function Composite	.014	.062	.116

$R^2 = .166$ for Model 1 ($p = .188$); R^2 change = .042 for Model 2 ($p = .811$)

Table 2.11

Summary of NA Regression Analysis for Variables Predicting Noncrux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.248	.067	
Associative Memory	-.088	.076	-.345
Model 2			
Constant	.151	.134	
Associative Memory	-.014	.119	-.056
Episodic Memory Composite	-.037	.056	-.425
Executive Function Composite	.003	.048	.036

$R^2 = .119$ for Model 1 ($p = .273$); R^2 change = .075 for Model 2 ($p = .699$)

Discussion

Effects of Learning Trials on Memory. NNA performance was examined across three learning trials. Initial analyses compared performance of stroke and control participants on Trial 1. Results showed that stroke participants' accomplishment performance was lower than that of controls. Both groups accomplished more crux than noncrux actions in the first trial, consistent with findings reported by Gold and Park (2009). With regard to error production, stroke participants made more errors overall than controls, particularly, more noncrux than crux errors, which is also consistent with results from Gold and Park (2009). Further, both groups made more omission than commission errors in the first trial.

One of the primary purposes of this experiment was to investigate the effects of practice on NNA performance in a sample of stroke participants. As hypothesized, accomplishment performance improved across trials and error rates decreased. This is consistent with previous literature examining the role of practice on learning a broad range of stimuli including lists of words (e.g., Farrell, 2012; Tulving, 1962) and skilled actions (Anderson, 1982, 1983, 1987; Rosenbloom & Newell, 1987). In a more recent study on acquisition of complex tool knowledge, both declarative memory (e.g., tool attributes) and procedural learning (e.g., motor skill acquisition) were shown to improve over multiple trials (Roy & Park, 2010).

This experiment is the first that I am aware of, that has examined the effects of practice on the acquisition of NNAs. It demonstrated that practice resulted in a reduction of both commission and omission error rates. It also showed that stroke participants were more likely to make errors of commission than omission for crux actions, but had a tendency to make more omission than commission noncrux errors. This pattern is consistent with what was found in Gold and Park (2009) who showed that participants under full attention produced slightly higher commission than omission error rates for crux actions (although not significant) as well as greater noncrux omission than commission error production over all attention conditions. This latter finding may result, in part, because crux actions are comprised of multiple associations, whereas, noncrux actions typically involve a single action paired with an object (Gold & Park, 2009; Park et al, 2012). In this way, if you do not properly encode a noncrux action, it will be omitted (e.g., take pin). Conversely, with crux actions, participants may remember some but not all associations and therefore would commit an error rather than omit that action (e.g., make a hole in the cup with a pencil instead of a pin).

Comparison of NA and NNA performance. Enactment of familiar, well-learned tasks was examined in both participants with stroke as well as age-matched controls. Participants with stroke accomplished fewer NA steps and made more errors overall than controls, consistent with what was demonstrated with other stroke studies (Park et al., 2012) including patients with right (Schwartz et al., 1999; Hartmann & Goldenberg, 2005) and left hemisphere stroke (Buxbaum et al., 1998; Hartmann & Goldenberg, 2005). Further, it was observed that participants with stroke made more omission than commission errors when performing NAs, where more errors were made on noncrux than crux actions, similar to what has been demonstrated in the literature (Cooper et al., 2005; Park et al., 2012).

Interestingly, different performance patterns emerged for the two groups in the comparison of NA and NNA T1 performance. Controls demonstrated greater accomplishment and produced fewer errors overall than participants with stroke on both NAs and NNA T1; however, they accomplished more actions and made fewer errors on NAs compared to NNAs. In contrast, participants with stroke accomplished a greater proportion of actions and made fewer errors overall on NNA T1 than NA enactment measures. These results are not consistent with the aforementioned hypothesis which predicted that in participants with stroke, NNA performance patterns would begin to resemble NA performance across learning trials as they became more familiar. However, findings from the current study suggest that NAs were not as well-known as previously hypothesized and consequently, performance was poorer than anticipated. Although unexpected, these findings may be reflective of the lack of opportunity participants with stroke had to perform everyday activities of daily living such as making coffee and a sandwich. Participants with stroke were recruited from a rehabilitation hospital, where they had spent a considerable amount of time in recovery (from 2 weeks to 3 months) and consequently, had not been participating in more instrumental activities of daily living (e.g., cooking). Thus, task knowledge may have been degraded or otherwise not as well represented in memory. For example, in the coffee making task, some participants neglected to place the coffee filter into the machine.

Multiple trace theory (Nadel & Moscovitch, 1997) proposes that every time an old memory is retrieved, a new memory trace is laid down. Thus, not performing a task for an extended period of time could result in degraded memory of NAs for the participants with stroke. An alternative explanation could be that NAs are more difficult than NNAs to perform by participants with neurological impairment. However, a study by Gold (2012) showed that participants with amnestic mild cognitive impairment (aMCI), accomplished more actions and made fewer errors on NAs than NNAs, although both NA and NNA performance was poorer overall when compared to control participants. The aMCI participants were living at home during the time of testing and so presumably had the opportunity to participate in activities of daily living such as cooking.

Association between NA and NNA enactment and neuropsychological test performance .

Comparing current findings to past research.

Previous research showed that NA omission errors were predicted by neuropsychological measures of episodic memory (Giovannetti et al., 2012; Park et al., 2012), but that commission errors were significantly associated with measures of executive function (Giovannetti et al., 2012). Further, greater NNA omission error rates were shown to be associated with lower scores on various episodic memory measures including the HVLT-R and the BVMT-R (Park et al., 2012), whereas, NNA commission error rates were significantly associated with measures of associative memory (Park et al., 2012). In the current study, performance on NAs as well as all three NNA learning trials was examined in relation to participant performance on neuropsychological test measures of associative memory, episodic memory, and executive function. Consistent with previous research, a greater number of NA and NNA omission errors were more strongly associated with lower scores on all three neuropsychological measures, especially the composite measure of episodic memory. In contrast, only NNA commission error rates were demonstrated to be more strongly associated with lower scores on episodic and associative memory measures, particularly in later trials. NA commission error rates were not shown to be significantly related to measures of cognitive functioning.

Correlations between NA and NNA enactment measures and neuropsychological test performance were further investigated through regression analysis. Differences emerged between NAs and NNAs. It was shown that participant episodic memory composite scores uniquely predicted NA omission crux and noncrux error rates, consistent with past research with NAs (Giovannetti et al., 2012). In contrast, participant associative memory scores were shown to uniquely predict NNA omission crux and noncrux error rates.

The unique role of associative memory for NNAs compared to NAs may be representative of developing associations between object, target, and action that are taking place during encoding and performance of novel actions that have not been performed previously. These results provide further evidence that successful NNA enactment is critically dependent on the formation of these new associations.

In contrast, for NAs, it can be assumed that the associations between object and action were formed prior to stroke and participation in the experiment, although the goal-subgoal structure of the task could possibly be somewhat degraded in the case of some participants. It is also possible that higher level goals are better established in NAs than NNAs and can therefore help support the enactment of these actions.

In the current study, NAs were demonstrated to be significantly related to the episodic memory composite score. Previous research has provided some evidence that episodic memory measures may comprise both episodic and semantic components. For example, several studies have demonstrated that on a multiple trial word-list measures similar to the HVLT-R, participants who showed better memory for the word-lists presented were able to better structure and organize the information presented (e.g., Bower, 1970; Farrell, 2012; Tulving, 1962). Further, a recent study with NAs has proposed that episodic memory failures (as measured by episodic memory tasks) may be indicative of degraded task knowledge (i.e., semantic knowledge about everyday tasks), where the failure to recall task goals could lead to everyday action impairment (Giovannetti et al., 2012). The aforementioned hypothesis might account for the current findings, especially when considering NA performance. As previously indicated, participants with stroke may have degraded task knowledge for everyday actions due to a lack of opportunity to participate in related actions. Thus, they were not able to engage in retrieval of these familiar activities for extended periods of time. Taken together, it can be hypothesized that NAs may be significantly related to episodic memory measures due to NA performance having both semantic and episodic elements.

Unexpectedly, results from the regression analysis showed that commission error rates were not significantly predicted by neuropsychological test measures of episodic memory, executive function, or associative memory. Inconsistencies with the current study and previous research with NAs (Bettcher, Giovannetti, MacMullen, & Libon, 2008; Giovannetti et al., 2012) and NNAs (Park et al., 2012) may be indicative of the heterogeneous nature of commission errors that are related to different cognitive processes. For example, commission errors can include errors of sequencing (executive function), object identification (episodic / semantic memory), as well as errors of grasp-spatial orientation (visuospatial processing). A study by Bettcher et al. (2008) showed that lower scores on tests of executive function were related to deficits in self-monitoring (error detection and correction) and consequently, higher rates of commission errors overall. However, they proposed that detection and correction of errors were each related to different measures of executive functioning. For example, *errors of detection* were associated with a measure of verbal fluency, whereas, *errors of correction* were related to a measure of visual-motor, organizational and constructional ability. Thus, the results from the current study as well as from previous research suggest that multiple cognitive processes, including those related to executive functioning and episodic memory, may contribute to the production of a commission error thereby weakening the relationship between any single neuropsychological measure and commission error rate.

Summary. Results from the current experiment indicate that although participants with stroke accomplished fewer actions and made more omission and commission errors than controls in NNA T1, performance did improve across the three learning trials. Correlational analyses showed that NNA omission error rates were associated with measures of episodic memory, associative memory, and executive function for all three learning trials. Commission errors were correlated with episodic memory in T2 and with associative memory in T2 and T3. Taken together, these results suggest differential contributions of each cognitive process at different stages of learning and enacting

NNAs. The next chapter will further examine the extent to which executive functions were involved in NNA performance by dividing attention either at encoding or at retrieval; thereby, allowing for an investigation of how manipulating executive functions when learning and enacting NNAs can influence NNA performance.

Chapter 3: The Effects of Attention on Learning and Performing Novel Naturalistic Actions (Experiment 2)

Introduction

Findings from Experiment 1 demonstrated that better performance on both episodic memory and executive function measures was associated with fewer errors for both NAs and NNAs. Further investigation of these correlations, through hierarchical regression analysis, showed that associative memory was the only significant predictor of NNA omission error rates. For NAs, episodic memory was the only significant predictor of omission error rates. Although executive function was not shown to uniquely predict NA and NNA performance in Experiment 1, a significant body of literature has demonstrated a role of executive function in both NA (e.g., Giovannetti et al., 2012) and NNA (e.g., Park et al., 2012) performance. Thus, the aim of the current experiment was to further investigate the role of executive function in NNAs by dividing attention either at encoding or retrieval. In this way, the degree to which executive functions were involved in NNA performance was explicitly manipulated by increasing attentional demands during study and performance and thereby permitting an examination of its implications for learning and performing naturalistic action.

Gold and Park (2009) used a dual-task procedure to investigate the role of attention in NNA performance. The authors proposed that performing a secondary attention-demanding task while encoding a NNA disrupted the formation of associative linkages between objects, actions, and goals, and this led to an increase in actions attempted, but performed incorrectly (i.e. commission errors). This interpretation is further supported by a study by Troyer, Winocur, Craik, and Moscovitch (1999) that demonstrated that dividing attention at study produced greater impairments in associative memory than in item recognition memory.

Experiment 2 aimed to further investigate the role of executive function and memory in learning new information by attempting to disrupt associations between actions and objects experimentally by dividing attention either at study (encoding) or during performance (retrieval) of a NNA in a group of participants with stroke and age- and education-matched controls. Similar to Gold and Park (2009), both groups viewed (encoded) and enacted (retrieved) an NNA in each of the following conditions: full attention at encoding and at retrieval (FF), divided attention at encoding, full attention at retrieval (DF), and full attention at encoding, divided attention at retrieval (FD). Each participant was required to construct three NNAs, one randomly selected for each attention condition. The secondary task used in this study is a modified version of the Elevator Counting task (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994; 1996) which is an adaptation of the tone counting procedure shown to be an attention-demanding task (Wilkins, Shallice, & McCarthy, 1987). Participants were asked to keep track of and verbally report the number of low tones presented in each trial. Unlike Gold and Park (2009), this experiment also obtained measures of episodic memory, associative memory, and executive function so that the roles of memory and executive function in learning and performing NNAs under divided attention conditions could be more directly examined.

Proposed Analyses and Predictions.

Effect of dividing attention at encoding or retrieval on NNA performance. A study from our lab examined the effects of dividing attention on NNA performance in a group of healthy undergraduates (Gold & Park, 2009). Results showed that dividing attention during encoding created a greater decline in NNA accomplishment crux and noncrux performance than when attention was divided during retrieval. This finding suggests that interfering with executive functioning may disrupt encoding of NNAs into memory, whereas disruption of executive function at retrieval has only a marginal effect on construction of a NNA. This pattern of findings is consistent with what has been shown in the dual-task memory literature (e.g., Anderson, Craik, Naveh-Benjamin, 1998; Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). Consistent with findings from this study as well as previous research, I hypothesized that selectively interfering with attention during encoding (DF) would result in a greater decline in NNA accomplishment crux and noncrux performance in comparison to when attention was divided during retrieval (FD) for both groups.

Gold and Park (2009) also showed that when attention was divided at encoding, undergraduates had higher commission than omission crux action error rates, but showed the reverse pattern for noncrux actions. The authors hypothesized that dividing attention while viewing NNAs disrupted processes involved in the encoding of viewed actions and in particular, interfered with the formation of associative links between objects, actions, and goals. This resulted in higher crux than noncrux commission error rates in NNAs (Gold & Park, 2009; see also Park et al., 2012) because crux actions have more associative links than noncrux actions (Schwartz et al., 1991). Based on these results, I expected similar patterns of NNA performance for crux and noncrux actions in the DF condition for both participants with stroke and age-matched controls.

Gold and Park (2009) examined secondary lag 1 audio task performance across attention conditions. Results showed that although enactment performance only marginally decreased in the FD condition, secondary task performance declined significantly when attention was divided at retrieval compared to performance at full attention. In contrast, the authors determined that there was no significant difference in secondary task performance between DF and FF, indicating no significant decline in performance when attention was divided at encoding. These findings are consistent with what has been shown in previous studies (e.g., Anderson et al., 1998; Craik et al., 1996; Fernandes & Moscovitch, 2000; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005) . The authors concluded that constructing a NNA required cognitive resources that subsequently disrupted secondary task performance when attention was divided at retrieval. In order to further investigate the role of attention on secondary task performance, I examined participant secondary task (i.e. tone counting task) performance across all three attention conditions. Consistent with previous research by Gold and Park (2009), I hypothesized that dividing attention at retrieval (FD) would have a larger effect on secondary task performance than either the FF or DF conditions, thus, indicating that NNA enactment requires attentional resources.

The relationship between NNA enactment measures across the three attention conditions (i.e., FF, DF, FD) and performance on episodic memory, associative memory and executive function measures was investigated in order to further clarify their respective roles in NNA performance. With regard to executive function, I hypothesized that poorer performance on executive function measures would be associated with impairments in NNA performance for all three attention conditions given the involvement of executive function in efficient encoding of new information into memory (see Anderson et al. 2000; Naveh-Benjamin, 2000). Findings from Gold and Park (2009), which showed that NNA performance was significantly impaired in DF compared to FD and FF conditions, also support the notion that executive processing is required during encoding of a NNA.

The importance of associative memory in NNA performance has been supported from findings from previous research as well as from the current study. Specifically, results from Experiment 1 showed that lower scores on a measure of associative memory were related to higher omission and commission error rates across three learning trials; however, a hierarchical regression analysis demonstrated that associative memory was a significant predictor of NNA omission error rates only. Findings were not shown with commission error rates. Although a study by Park et al. (2012) obtained a significant relationship between lower associative memory scores and higher NNA commission error rates. Thus, the role of associative memory in commission error production is uncertain.

Another factor that has been shown to play a role in increased commission error rates is impairment in executive functioning where poorer performance on executive function measures was shown to be associated with greater NA omission and commission error rates (Bettcher at al., 2008; Giovannetti et al., 2012; Kessler et al., 2007). Taken together, these findings provide support for the hypothesis that associative memory and executive function would be associated with NNA commission error rates, particularly in divided attention conditions. Differences across conditions may be explained by a differential contribution of executive function and associative memory processes when attention is divided at encoding and at retrieval.

Method

Participants.

Stroke participants. Eighteen stroke patients, who comprise *Stroke Group 2*, who had sustained a single unilateral stroke (determined by patient records) were recruited from St. John's Rehabilitation Centre (see Table 3.1). Participants fell between the ages of 52 and 84 (M = 71.2, SD = 9.5). Inclusion and exclusion criteria were identical to those in Study 1.

Aged-matched controls. An age-matched control group (distinct from the group presented in Study 1, consisting of 18 healthy older adults was recruited from the Montreal and Toronto community through flyers and word-of-mouth (see Table 3.1). Participants fell between the ages of 58 and 74 (M = 66.1, SD = 4.7) and scored in the normal range on the Modified Mini Mental Status Examination (3-MS), a general test of cognitive functioning ($M = 95.3$, $SD = 4.2$). Inclusion and exclusion criteria were identical to those in Experiment 1.

Table 3.1 summarizes characteristics of both stroke and age-matched control participants. A one-way analysis of variance (ANOVA) with the variables of age, education and the between-subjects factor of group (controls, stroke) showed no significant differences between groups on age and education. An independent t-test confirmed a significant difference in general cognitive functioning between controls ($M = 95.3$, $SD = 4.2$) and participants with stroke ($M = 87.6$, $SD = 11.0$), where the two groups differed significantly, $t(34) = 2.8$, $p = .008$.

Stimuli.

Primary task. The following three NNAs were constructed by each participant: birdfeeder, ear guitar, and mock volcano. On average, the number of scripted actions necessary to complete each task was 14.67 ($SD = 6.66$) crux actions and 57.00 ($SD = 17.69$) noncrux actions. Each NNA had a mean number of 8.67 ($SD = 0.58$) target objects presented as well as 4.67 ($SD = 0.58$) distractor items that were either functionally similar (e.g., stapler instead of tape) or physically similar (e.g., ice cream scoop instead of teaspoon).

Secondary task. The secondary task used in this experiment was a modified version of the Elevator Counting Task (Robertson et al., 1994; 1996). In this task, a series of high and low tones were pre-recorded within 15-18 s intervals at a rate of one tone presented every 2 seconds. The number of tones presented ranged from five to nine tones, with a greater proportion of lower to higher tones within each series. Participants were required to keep track of the number of low tones they heard and indicated verbally how many low tones were presented after each series. Participants who achieved 50% or more answers correct during the calibration portion of the experiment, continued with the 2 second rate. Otherwise, participants were presented series of tones at a rate of one tone every 5 seconds for the experimental portion in order to control for task difficulty. Similarly to the 2-second rate of presentation, the number of tones presented ranged from five to nine tones, with a greater proportion of lower to higher tones within each series. All but one participant with stroke (LM) and all control participants continued with the 2-second rate. The slower rate was performed to ensure that participants who were unable to perform the secondary task with at least 50% accuracy could participate in the experiment.

Measures of performance. Enactment performance was scored using the same protocol and dependent measures as those used in Study 1. Specifically, accomplishment, omission error, and commission error rates were calculated for both crux and noncrux actions across all three attention conditions. Secondary task performance across all three attention conditions was calculated by taking the number of tone-counting trials reported correctly divided by the number of trials presented. In addition, a secondary task full attention composite score was calculated by averaging each participant's secondary task performance in the full attention condition with each full attention baseline performance measure across all attention conditions.

Inter-rater reliability was assessed using an independent rater who scored 30% of the data. The ICC for the accomplishment score was 0.94 for crux actions, $F(8, 8) =$

16.63, $p < .001$, and 0.97 for noncrux actions, $F(8, 8) = 39.03$, $p < .001$. The ICC for the omissions was 0.94 for crux actions, $F(8, 8) = 17.27$, $p < .001$, and 0.98 for noncrux actions, $F(8, 8) = 52.13$, $p < .001$. Finally, the ICC for the commissions was 0.99 for crux actions, $F(8, 8) = 134.62$, $p < .001$, and 0.96 for noncrux actions, $F(8, 8) = 22.21$, $p < .001$.

Design. This study used a mixed design in which there were three levels of the within-subjects factor of attention. The FF condition required participants to view and enact the NNA at full attention. The DF condition involved dividing attention at encoding, whereas retrieval of the NNA was performed at full attention. Finally, the FD condition required participants to view the NNA at full attention and enact the NNA while under divided attention. These attention conditions were presented to each participant in the two groups (i.e., age-matched controls, participants with stroke). Each participant enacted the construction of three NNAs, counterbalanced across each attention condition. Under dual-task conditions, participants were required to either view or enact each NNA while performing the secondary tone counting task. The order of dual-task conditions was counterbalanced across participants as well as across NNAs (sees Appendix I) for order of presentation).

Procedure.

Enactment. Prior to the test phase of the experiment, familiarity with the NNAs was assessed using the same questionnaire as in Study 1 (See Appendix B). The only difference was that the questions were read out loud by the experimenter. Then, there was a practice phase of the experiment in which all participants practiced performing the tone counting task, the secondary task, at full attention. In addition, to ensure comprehension of the NNA task requirements, there was a practice NNA trial, in which each participant viewed and subsequently enacted a practice NNA, building a pinhole camera, at full attention.

In the test phase of the study for each of the three attention conditions, participants were instructed to view a video of an actor constructing an NNA after which they were required to build the NNA in exactly the same way that they saw the actor do it in the video. In the DF condition, participants were told they would view a video of the NNA being constructed while performing the secondary task. In the FD condition, participants were told that they would enact the construction of the NNA while performing the secondary task. They were told that although both tasks were important, they were to give priority to the tone counting task in the event that they found it difficult to do both tasks simultaneously. Participants were asked to perform the secondary tone counting task at full attention before beginning the three experimental enactment trials. Order of presentation of the three attention conditions was counterbalanced across participants (see Appendix I for counterbalance schedule).

Standardized psychological tests. In addition to experimental measures, both participants with stroke and healthy age-matched controls completed a battery of neuropsychological tests. These tests included measures of general cognitive function, verbal memory, visuospatial memory, and executive function (see Appendix F). Stroke participant performance on individual neuropsychological tests comprising each of the following three measures is listed in Appendix J.

Episodic memory composite. The episodic memory composite was derived using the same measures and statistical approach as those used in Experiment 1.

Executive function composite. The executive function composite measure was calculated by averaging the z-scores of the following measures of executive function: Trail Making Test part B completion time, Victoria Stroop ratio of interference score (time to state color of words printed in different color ink/ time to state color of colored dots), Victoria Stroop color word completion time, and Victoria Stroop color word error score.

BVMT –R association scores. BVMT-R associative memory recall scores were calculated in the same way as in Experiment 1.

Approach to Data Analyses. Participant enactment performance was scored and analyzed for NNAs. Approach to statistical analysis was similar to that used in Study 1. Further, enactment performance was compared to participant performance on a battery of neuropsychological test measures in order to examine the relationship between cognitive functioning and enactment performance (see above).

Results

Enactment.

NNA accomplishment performance. Participant performance on NNAs was examined across all three attention conditions (see Figure 3.1). Preliminary analyses showed that several of the participants with stroke seemed to perform at or close to the same level as controls. For this reason, stroke participants were divided into low and high error producers based on a median split on total error production across all three attention conditions. This was done to increase the sensitivity for this study. A repeated measures ANOVA with within-subjects factors of attention (FF, DF, FD), action type (crux, noncrux), and between-subjects factor of group (low error producers, high error producers, controls) obtained a significant effect of group, $F(1, 33) = 41.89, p < .000, \eta_p^2 = .717$. Post-hoc t-tests revealed that high error producers accomplished fewer actions overall ($M = 43.25$, $SD = 12.34$) than both low error producers ($M = 74.35$, SD =6.66), $t(16) = 6.65, p < .000, \eta_p^2 = .734$ and control participants ($M = 74.41$, $SD = 8.07$) $t(25) = 7.912, p < .000, \eta_p^2 = .715$. Accomplishment performance between low error producers and age-matched controls was not significantly different.

A significant two-way interaction between attention condition and group, $F(4, 66) = 7.76, p = .009, \eta_p^2 = .205$ was also demonstrated. Contrary to my hypothesis, follow-up analyses confirmed that there was no significant difference in accomplishment performance across all three attention conditions for high and low error producers. In contrast, for controls, accomplishment performance in the DF condition ($M = 65.15$, $SD = 13.52$) was significantly lower than performance in the FF condition ($M = 80.79$, $SD =11.21$), $t(17) = 5.63, p < .000, \eta_p^2 = .651$ and in the FD condition FD ($M =77.31$, $SD = 10.36$) $t(17) = -3.37, p = .004, \eta_p^2 = 401$. Accomplishment performance did not differ between the FF and FD condition in control participants.

In addition a significant two-way interaction was obtained between action type and group, $F(2, 33) = 11.32, p < .000, \eta_p^2 = .407$. Follow-up analyses by group revealed that for low error producers and controls, there was no significant difference between crux and noncrux action accomplished. Conversely, high error producers accomplished a higher proportion of noncrux (M = 45.85, SD = 11.25) than crux (M = 32.82, SD = 17.14) actions, $t(8) = -5.25, p = .001, \eta_p^2 = .775$. Finally, a main effect of attention condition was obtained, $F(2, 32) = 6.27, p = .005, \eta_p^2 = .282$.

In summary, these findings indicate that high error producers accomplished fewer actions than low error producers and controls. There was no difference in accomplishment performance between low error producers and controls. Somewhat surprisingly, results showed that only controls accomplished significantly fewer actions in the DF condition than in the FF and FD conditions. Thus, contrary to my hypothesis, high error producers did not exhibit differentially poorer performance when attention was divided at encoding when compared to low error producers and controls. Finally, high error producers were shown to accomplish more noncrux than crux actions, whereas there was no difference in action type performance for low error producers and controls.

NNA error analysis. NNA error production was analyzed in order to determine whether there were differences in error patterns produced between the three groups (high error producers, low error producers, controls) when attention condition was manipulated (see Figure 3.2). A repeated measures ANOVA with within-subjects factors of attention (FF, DF, FD), error type (omission, commission), and action type (crux, noncrux) and the between-subjects factor of group (high error producer, low error producer, and controls) obtained a significant main effect of group, $F(2, 33) = 22.38, p < .000, \eta_p^2 = .576$. Follow-up t-tests confirmed that high error producers make significantly more errors overall (M = 40.60, SD = 5.83) than low error producers (M = 18.0, SD = 7.18), $t(16) = -7.34$, p < .000, $\eta_p^2 = .771$ and age-matched controls, (M = 23.90, SD = 8.42), $t(25) = 5.32$, p < .000, η_p^2 = .531. There was no significant difference observed between low error producers and controls. In addition, a significant main effect of attention condition was found, $F(2, 32) = 6.48$, $p = .004$, η_p^2 = .288. Follow-up post-hoc t-tests confirmed that participants made significantly more errors in the DF condition M = 63.69, SD = 25.98) than both the FF *(M* = 42.32, SD = 25.96), $t(35) = -4.17$, p < .000, η_p^2 = .332 and FD conditions (M = 47.91, SD = 30.54), $t(35) = 3.29$, p < .000, η_p^2 = .236. There was also a significant effect of action type, $F(1, 33) = 9.38$, $p = .004$, η_p^2 = .221, where participants were shown to have made more crux than noncrux type errors overall, but this did not interact with group, $F(2, 33) = 2.56$, $p = .092$, η_p^2 = .135.

Additionally, a significant three-way interaction was found between attention condition, error type, and action type, $F(2, 32) = 6.42$, $p = .005$, η_p^2 = .286. Follow-up ANOVAs by action type with within-subjects factor of attention condition and error type demonstrated that for crux actions, a two-way interaction was observed between attention condition and error type, $F(2, 70) = 3.57$, $p = .033$, η_p^2 = .093. Post-hoc analysis confirmed that in the FF condition, participants made more commission (M = 33.27, SD = 35.21) than omission (M = 13.10, SD = 13.27) crux errors, $t(35) = -3.50$, p = .001, η_p^2 = .259. Similarly, in the DF condition, participants made significantly more commission (M = 53.04, SD = 43.14) than omission (M = 23.77, SD = 16.38) crux errors, $t(35) = -3.69$, p = .001, η_p^2 = .280. In contrast, there was no difference in commission and omission crux error rates in the FD condition. In addition, there was a significant main effect of attention condition, $F(2, 70) = 8.95$, $p < .000$, η_p^2 = .294, where participants made significantly more crux errors in the DF condition (M = 38.41, SD = 22.30) than the FF condition ($M = 23.19$, $SD = 20.22$), $t(35) = -3.15$, p = .003, $\eta_p^2 = .221$ as well as the FD condition ($M = 24.41$, $SD = 15.60$), $t(35) = 3.78$, p = .001, $\eta_p^2 = .290$. There was also a significant main effect of error type $F(1, 35) = 19.47$, $p < .000$, $\eta_p^2 = .357$, where participants made more commission than omission crux errors.

For noncrux actions, a repeated measures ANOVA with within-subjects factors of attention condition and error type obtained a significant main effect of attention, $F(2, 70) = 9.78$, $p < .000$, $\eta_p^2 = .218$. Follow-up t-tests confirmed that participants made more noncrux errors in the DF condition ($M = 30.30$, $SD = 12.33$) than the FF condition ($M = 19.59$, $SD = 12.21$), $t(35) = -4.82$, p < .000, $\eta_p^2 = .399$ as well as the FD condition ($M = 23.87$, $SD = 16.05$), $t(35) = 2.63$, p = .012, $\eta_p^2 = .165$. There was also a significant main effect of error type $F(1, 35) = 4.23$, $p = .047$, $\eta_p^2 = .108$, where participants made more omission than commission noncrux errors.

In summary, participants made significantly more crux and noncrux errors in the DF condition than in the FF and FD conditions, but in contrast to my hypothesis, although high error producers made more errors overall, they did not perform differentially worse in divided attention conditions than low error producers and controls. For crux actions, participants made more commission than omission crux errors. Further analyses showed that participants made more commission than omission crux errors in the FF and DF attention conditions, but there was no difference in the proportion of omission and commission crux errors produced in the FD condition. In contrast, they made more omission than commission noncrux errors overall.

Secondary task analyses. A preliminary analysis was done of participant secondary task performance on full attention baseline and experimental conditions in order to determine if there was a difference across conditions. It was demonstrated that there was no difference in secondary task baseline and experimental performance in the FF condition. Participant performance on the tone counting task was then examined across three attention conditions; including, at full attention (composite score derived from averaging performance across three baseline and one experimental condition), during the encoding of a NNA (DF), and while enacting a NNA (FD) (see Figure 3.3). A repeated measures ANOVA with within-subjects factor of attention (FF, DF, FD) and between-subjects factor of group (high error producers, low error producers, controls) obtained a significant main effect of group, $F(2, 33) = 4.73$, $p = .016$, $\eta_p^2 = .223$. Post-hoc analyses showed that high error producers had significantly lower secondary task performance scores ($M = 72.53$, $SD = 11.41$) than controls ($M = 84.13$, $SD = 9.57$), $t(25) = -2.79$, p = .025, $\eta_p^2 = .237$. There was no significant difference in secondary task performance between the other groups.

There was also a main effect of attention, $F(2, 66) = 54.71$, $p < .000$, $\eta_p^2 = .624$. Follow-up t-tests confirmed that participant secondary task performance was significantly lower in the FD condition ($M = 55.85$, $SD = 24.03$) than in the DF condition ($M = 85.46$, $SD = 17.20$), $t(35) = 6.37$, p < .000, $\eta_p^2 = .537$, and FF condition ($M = 95.86$, $SD = 7.54$), $t(35) = 9.90$, p < .000, $\eta_p^2 = .737$; thus, indicating that participant performance dropped when attention was divided during NNA enactment performance. Participant secondary task performance was also shown to be significantly lower in the DF condition than FF,

$t(35) = 3.52$, $p = .001$, $\eta_p^2 = .262$. Taken together, these results indicate that secondary task performance significantly declined from FF conditions when participants were asked to complete the tone counting task either while viewing or enacting the NNA. This is inconsistent with past research which showed a decline in secondary task performance only when attention was divided at retrieval.

Examining NNA enactment completion times for each of the three attention conditions. Participant NNA enactment completion times (in seconds) for each attention condition (FF, DF, FD) are presented separately for the three groups of participants in Figure 3.4. A repeated measures ANOVA with within-subjects factor of attention condition (FF, DF, FD) and between-subjects factor of group (high error producers, low error producers, controls) demonstrated a significant interaction between attention condition and group, $F(4, 62) = 2.59$, $p = .046$, $\eta_p^2 = .143$. Post-hoc analyses, which looked at differences in NNA enactment times across attention conditions within each group, showed that there was no significant difference in NNA enactment times across all three attention conditions for low error producers and age-matched controls. In contrast, high error producers had significantly longer NNA enactment completion times in the FD condition ($M = 399.57$, $SD = 368.22$) than the DF condition ($M = 157.33$, $SD = 47.84$). There were no further differences in completion time across attention conditions for high error producers. Finally, there was a significant main effect of attention, $F(2, 62) = 5.39$, $p = .007$, $\eta_p^2 = .148$.

Visual inspection of Figure 3.4 revealed that FD variability was much greater for high error producers in particular, consistent with Levene's test for the FD condition which was significant, $F(2, 31) = 6.537$, $p = .004$, indicating that group variances were not equal and that the assumption of homogeneity of variance had been violated. Thus, the Wilcoxon signed-rank test, a non-parametric equivalent of the dependent t-test was then carried out to further investigate whether FD completion times significantly differed from FF and DF completion times. Across participants, FD completion times were significantly higher (*Mdn* = 162.0) than FF completion times (*Mdn* = 148.0), $z = -2.84$, $p = .005$, $r = - 0.34$. Further analyses looked at the difference between FF and FD completion times within groups. It was demonstrated that in high error producers, participants had higher FD (*Mdn* = 220.0) than FF (*Mdn* = 145.0) completion times, $z = -2.37$, $p = .018$, $r = - 0.63$. There were no significant differences observed between FF and FD completion times in low error producers and controls. Additionally, it was shown that high error producers had higher FD (*Mdn* = 220.0) than DF (*Mdn* = 158.0) completion times, $z = -2.03$, $p = .043$, $r = -0.54$. There was no other overall or within group difference observed between FD and DF completion times.

Taken together, these results demonstrated that high error producers had significantly longer NNA completion times in the FD condition than within the DF and FF conditions. There was no difference in NNA completion times across attention conditions for either low error producers or controls.

Comparison between NNA enactment across attention conditions and neuropsychological test performance. A summary of the Pearson correlational coefficients between NNA enactment error rates (i.e., rates of omission and commission) and performance on neuropsychological assessment measures in all participants is presented in Table 3.2. NNA enactment measures across the three attention conditions were separately compared to participant episodic memory and executive function composite scores as well as to participant performance on an associative memory measure.

For omission errors, higher scores on episodic memory composite measures were significantly associated with lower crux and noncrux omission error rates in all three attention conditions. Similarly, higher scores in the executive function were significantly correlated with lower crux and noncrux omission errors in the FF and DF condition and with lower crux omission errors in the FD condition. In contrast, there was no association observed between crux and noncrux omission error rates and overall participant performance on an associative memory measure.

For commission errors, higher scores on episodic memory measures were significantly correlated with lower noncrux commission error rates in the FD condition only. Alternatively, greater crux commission error rates were shown to be significantly associated with poorer associative memory in the FF condition. Commission error rates were not shown to be significantly correlated with executive function in any of the three attention conditions.

Taken together, these results suggest a different pattern of correlations for omission and commission error rates. Overall, stroke participant omission error rates appear to be highly related to performance on episodic and executive function composite measures, across all three attention conditions. Omissions were not shown to be correlated with performance on an associative memory measure. In contrast, commission crux error rates were shown to be associated with performance on an associative memory measure in the FF condition. They were not demonstrated to be correlated with performance on measures of executive function. However, a significant correlation was also observed between noncrux commission error rates and episodic memory composite scores in the FD condition.

Table 3.1

Participant Characteristics

	Number (N)	Mean Age (SD)	Education (Years) (SD)	3-MS (SD)
Age-matched controls	18	66.1 (4.7)	12.3 (4.4)	95.3 (4.2)
Participants with Stroke	18	71.2 (9.5)	13.7 (3.5)	87.6 (11.0)

Note. 3-MS = Modified Mini Mental State Examination.

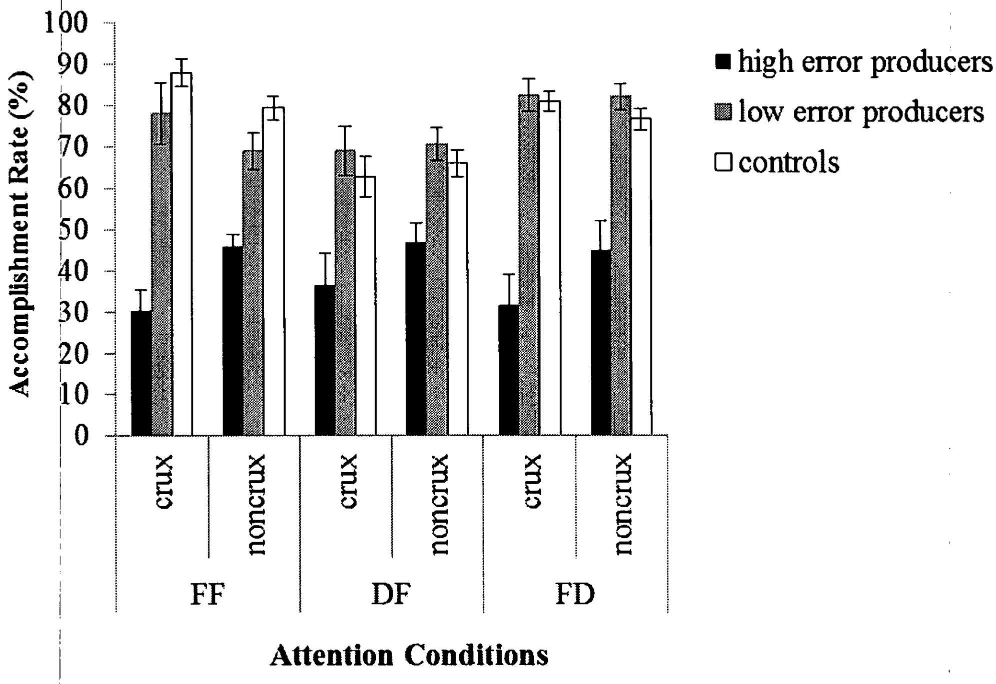
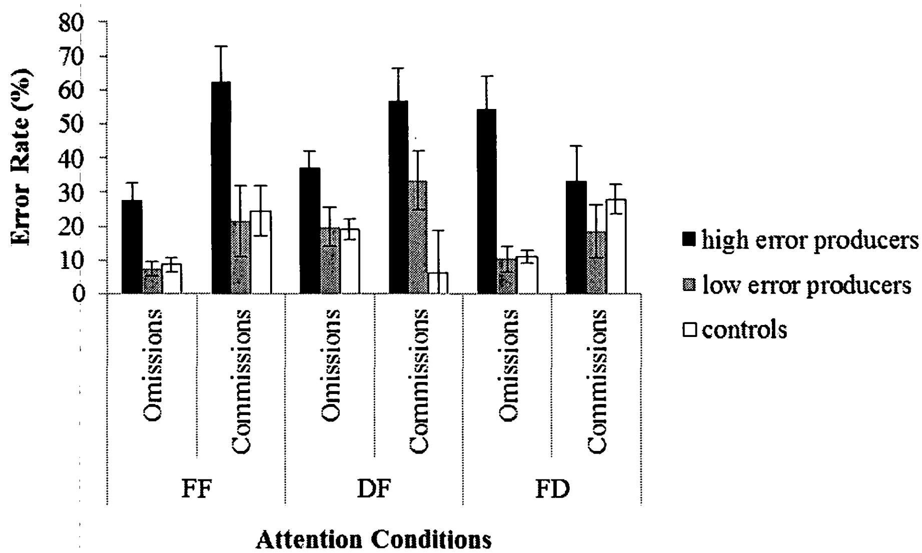


Figure 3.1. Accomplishment Rates (+/- SE) across three attention conditions.

A.



B.

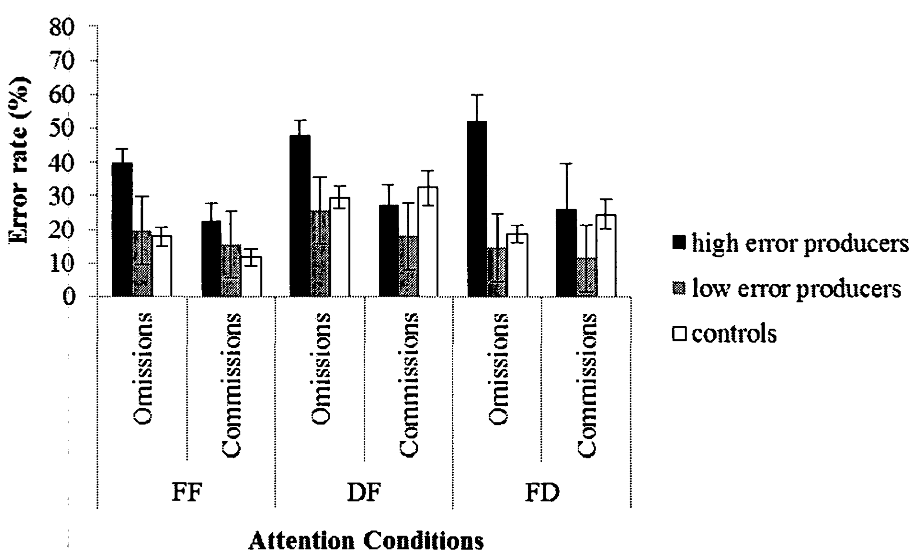


Figure 3.2. Crux (a) and Noncrux (b) error rates across three attention conditions. A. Crux error rates (+/- SE). B. Noncrux error rates (+/- SE).

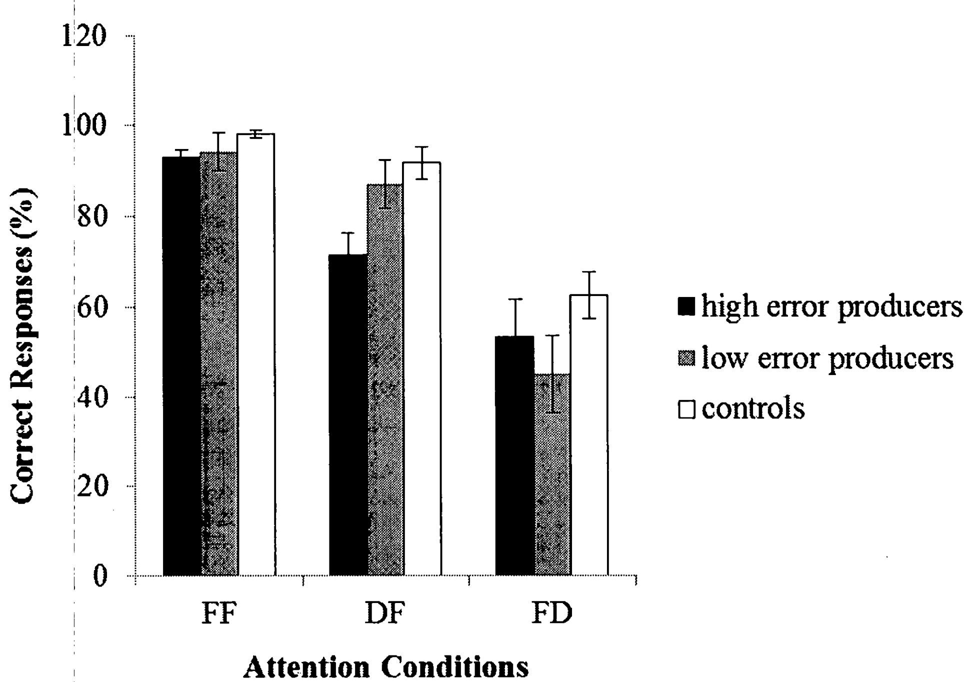


Figure 3.3. Secondary task correct response rates (+/- SE) across three attention conditions.

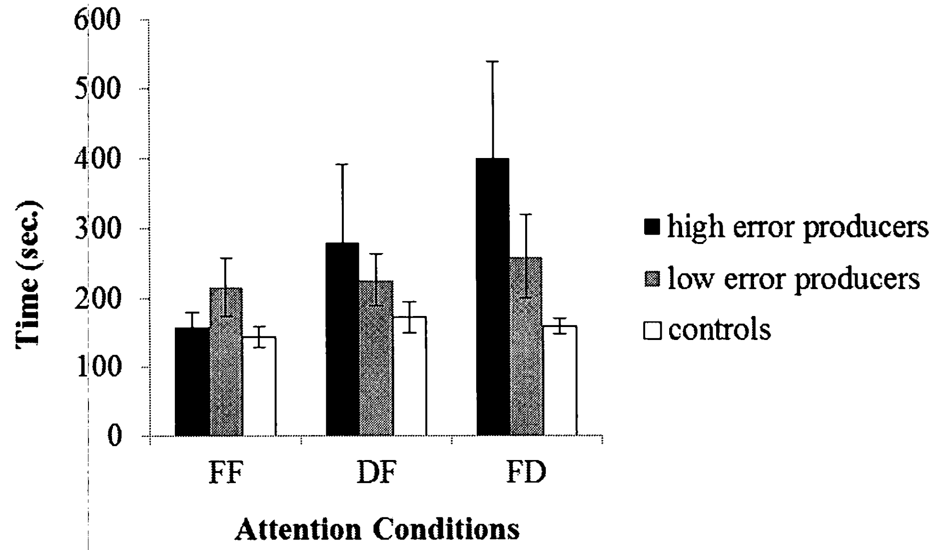


Figure 3.4. NNA enactment completion rates (+/- SE) across three attention conditions.

Table 3.2

Comparison between Neuropsychological Test Performance and NNA Enactment Measures

Behavioural Measures	EpMem	ExFn	Assoc. Mem.
FF Om Crux	-.452**	-.346*	-.163
FF Om Noncrux	-.536**	-.392*	-.267
FF Comm Crux	-.166	-.053	.337*
FF Comm Crux	-.084	-.014	-.209
DF Om Crux	-.616**	-.439*	-.209
DF Om Noncrux	-.576**	-.345*	-.202
DF Comm Crux	.095	.104	-.256
DF Comm Noncrux	-.093	-.071	-.157
FD Om Crux	-.520**	-.402*	-.174
FD Om Noncrux	-.432*	-.263	-.140
FD Comm Crux	-.106	-.104	-.275
FD Comm Noncrux	-.411*	-.383	-.229

Note. Om. = Omission Error; Comm. = Commission Error; EpMem. = Episodic Memory Composite; ExFn. = Executive Function Composite; Assoc. Mem. = Associative Memory.
$^{*}p \leq .05$, $^{**}p \leq .01$.

Discussion

Enactment performance. The purpose of this experiment was to investigate the effects of dividing attention at encoding or at retrieval of a NNA in a group of participants with stroke compared to a group of age- and education-matched controls. Although the role of divided attention in NNAs has been previously studied in a group of undergraduates, to my knowledge, no studies of NNAs have examined the effects of divided attention in older or neurological populations. An additional novel feature of this experiment was that the cognitive processes involved in performing NNAs under divided attention conditions were investigated by comparing enactment to performance on neuropsychological test measures of episodic memory, associative memory, and executive function.

Results showed that overall, participants made more crux and noncrux errors in the DF condition than in the FF and FD conditions, suggesting that dividing attention at encoding was more disruptive than dividing attention at retrieval to NNA enactment. This finding is generally consistent with Gold and Park (2009) as well as other studies of attention (e.g., Anderson et al., 1998; Baddeley et al., 1984; Craik et al., 1996; Fernandes & Moscovitch, 2000; Naveh-Benjamin et al., 2005). Findings also revealed a different error pattern for crux versus noncrux errors. Specifically, participants made more commission than omission errors for crux actions, but showed the reverse pattern for noncrux errors. These findings are consistent with what was shown with previous studies looking at NNA performance (e.g., Gold & Park, 2009; Park et al., 2012) as well as with results in Experiment 1.

Secondary task performance. Overall, participant secondary task performance was lower in the FD condition than in the FF and DF conditions, consistent with what has been shown in other divided attention studies with NNAs (e.g., Gold & Park, 2009). In addition, secondary task performance in the DF condition significantly declined. Although this is different from what was demonstrated in Gold et al. (2009), other studies (Craik et al., 1996; Naveh-Benjamin, Craik, Guez, & Don, 1998; Naveh-Benjamin & Guez, 2000) also found a small but significant impairment in secondary task performance in the DF condition relative to FF. Taken together, these results indicate that dividing attention at either encoding or retrieval led to decrements in secondary task performance with a greater decrement in the FD than DF condition.

NNA completion times. Enactment completion times were examined across all three attention conditions. It was shown that high error producers had significantly longer NNA enactment times in the FD condition than in the FF and DF attention conditions. There was no significant difference between FF and FD completion times in low error producers and controls. Thus, overall higher NNA completion times in the FD versus FF condition in high error producers may be suggestive of increased difficulty performing both tasks concurrently.

Multitasking can be carried out by rapidly switching between two or more tasks. It is possible that high error producers were slower in switching back to NNA enactment following secondary task responding. Previous research looking at divided attention in a group of younger and older adults showed that impairments in multitasking, due to disruptions in working memory performance through the introduction of a secondary task, were the result of a deficit in efficiently switching between functional brain networks (Clapp, Rubens, Sabharwal, & Gazzaley, 2011). A careful look at the videos of high error producers showed that some of these participants appeared to stop enacting the NNA in order to respond to the secondary task, and then returned to performing a step of the NNA until they produced their next secondary response. In other words, high error producers laboriously switched between the two tasks and this resulted in increased NNA completion times in the FD condition. Thus, high error producers solved the high attention demands by switching from one task to another instead of trying to complete both the primary and secondary tasks at the same time. In contrast, low error producers and controls showed no difference in NNA completion times across attention conditions, suggesting that they were able to concurrently complete both tasks, or could switch rapidly between the two tasks.

The strategy used by high error producers to switch between tasks did not impair NNA enactment perhaps because in the course of performing these tasks, objects are placed in front of the participants. A participant would begin construction and subsequently pause to respond to the secondary task. They would then resume building the NNA at which point, the task would be partially completed and the participant would be able to easily see where they were in their construction. Thus, working memory load would be reduced due to considerable feedback in the form of visual cues showing task materials and partially constructed NNAs. In summary, the current results demonstrated that although enactment and secondary task performance did not decline differentially for high error producers relative to other groups, they tended to take significantly more time to complete NNAs in the FD condition, possibly due to impairments in task switching efficiency.

NNA enactment compared to neuropsychological test performance. Results from the current study showed that NNA enactment measures, particularly crux and noncrux omission errors, were significantly related to participant performance on episodic memory measures across all three attention conditions. These findings are consistent with Experiment 1, which showed an association between better performance on episodic memory measures and lower NNA omission and commission error rates across the three learning trials. Thus, these findings in addition to what was shown in Experiment 1 may provide further evidence that our measure of episodic memory played an important role in the enactment of NNAs. Further, the relationship between performance on episodic memory measures and omission error rates was also reported in other NNA studies (i.e., Park et al., 2012).

Executive function was also demonstrated to be significantly associated with crux and noncrux omission error rates both at full attention and when attention was divided at encoding. Further, a significant correlation between executive function composite scores and omission crux error rates were observed when attention was divided at retrieval. These findings are consistent with results from Experiment 1 which showed that higher NNA omission error rates were associated with poorer performance on measures of executive function. Interestingly, executive function measures were not more strongly associated with NNA performance in divided attention compared to full attention conditions. Further, the hypothesis that poorer performance on executive function measures would be associated with greater NNA commission crux error rates, particularly when attention was divided, was not supported. Although these findings suggest a role of executive function in NNA encoding and enactment, their specific involvement in commission error rate was not shown. This finding is unexpected for several reasons. First, it had been hypothesized that as crux actions have more associative linkages than noncrux actions, a disruption of controlled or executive processes involved in efficient encoding may lead to an action being attempted, though with error, resulting in a commission error (Gold & Park, 2009). Second, the aforementioned hypothesis was supported by previous studies which have shown that commission error rates were associated with measures of executive function (Giovannetti et al., 2012; Bettcher et al., 2008; Kessler et al., 2007). A possible explanation for this current finding would be that the composite measure of "executive function" may not have been a sensitive enough measure. A study looking at the ecological validity of executive function measures proposed a fractionation of executive functions, where different tests were shown to measure different cognitive processes (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). In this way, it is possible that the executive function composite measure, which comprised the average of several executive function test scores, exhibited decreased sensitivity for a particular cognitive or "executive" process.

Remarkably, associative memory was not shown to be strongly related to NNA performance measures. Crux commission error rates were significantly correlated with associative memory at full attention only. There were no other significant associations. This finding is consistent with Park et al. (2012), who showed that higher crux and noncrux NNA commission error rates were associated with lower scores on a measure of associative memory at full attention. However, this is inconsistent with Experiment 1 results, which showed a strong correlation between associative memory composite scores and NNA omission error rates in the first trial, at full attention. This inconsistency across studies, particularly in FF and FD conditions, may be due to differences in the sensitivity of NNA performance measures in the two studies. In Experiment 1, there were four observations per participant for each condition (i.e., four NNAs enacted across T1, T2, and T3). In contrast, in the current experiment, participants enacted only one NNA per condition (i.e., FF, DF, and FD); thus, possibly yielding a less sensitive measure of NNA performance. Further, secondary task performance could have interfered with associative memory functioning, especially in the DF condition.

As in Experiment 1, results from the current experiment showed a stronger association between neuropsychological test measures and omission error rates than with commission error rates. This finding may have occurred for several distinct reasons. For example, in the ear guitar task, a commission error is assigned for several different kinds of errors including taking the wrong object (e.g., plastic cup instead of Styrofoam cup), performing the steps of the task in the wrong sequence (e.g., make a hole in the cup with a pencil and then a pin), as well as not adhering to the proper spatial dimensions require for successful task completion (e.g., not cutting enough string). The types of errors in turn may result from a variety of cognitive impairments. In this way, commission errors would not be associated with a specific cognitive process as measured by a particular neuropsychological test.

Summary. Findings from this experiment showed that although dividing attention at encoding and retrieval resulted in overall poorer NNA performance in the DF compared to FF and FD conditions, high error producers did not exhibit differentially poorer NNA performance in the DF condition compared to low error producers and controls. However, high error producers had higher NNA completion times in the FD condition compared to the FF and DF conditions, suggesting impairments in task switching efficiency. Correlational analyses demonstrated that executive function and episodic memory were associated with omission error rates in all three attention conditions. In contrast, commission errors were associated with associative memory in FF condition and episodic memory in the FD condition. Together with results from Experiment 1, these findings provide more evidence of the involvement of episodic memory, associative memory, and executive function in NA and NNA performance. The following chapter will examine which brain regions were associated with NA and NNA error measures. In particular, I wanted to investigate whether the neural regions thought to be associated with episodic memory, associative memory, and executive function were associated with NA and NNA error measures.

Chapter 4: Neuroanatomical Substrates of Routine and Novel Naturalistic Action Performance (Experiment 3)

Introduction

This experiment examined whether particular brain regions were related to enactment performance through an analysis of neuroimaging data of stroke participants from Experiments 1 and 2. Specifically, the influence of lesions on NA and NNA enactment performance measures was investigated in order to determine whether enactment scores significantly differed between stroke participants with and without damage for each voxel (Rorden & Karnath, 2004).

As previously outlined, based on previous studies, it is reasonable to hypothesize that the neural correlates of memory and executive function may be associated with impaired performance of NAs and NNAs (e.g., Park et al., 2012; Schwartz et al., 1991). The importance of episodic and associative memory is also suggested by Experiments 1 and 2.

In addition, findings from a recent study suggest that structures of the basal ganglia, a brain region known to be involved in performance of skilled action, may be associated with impaired enactment of NAs and NNAs (Park et al., 2012). That study investigated the influence of lesions on NNA crux accomplishment performance to determine whether accomplishment scores significantly differed between patients with and without damage for each voxel (Rorden & Karnath, 2004). It should be noted that the subject data examined in Park et al. (2012) was a small subset of the full sample of participants with stroke investigated in the current study. The authors observed that damage to either the left or right hemisphere or damage to subcortical regions including the globus pallidus, putamen, and claustrum, which are primary components of the basal ganglia, as well as damage to the thalamus, was associated with impaired accomplishment of NNAs. These findings were not found to be significant, despite not being corrected for multiple comparisons and thus, all results were viewed as exploratory. Based on these and other findings, the authors proposed that NNA enactment depends upon episodic and motor-procedural memory. In the next section, I will describe in more detail the neural regions believed to be associated with episodic memory, executive function, and motor-procedural memory. I hypothesized that damage to any of these regions would result in impaired NA and NNA performance.

Analyses and predictions. The neuroanatomical substrates of recollection and familiarity were outlined in a model proposed by Aggleton and Brown (1999), in which it was hypothesized that the "extended hippocampal-diencephalic system" functioned to mediate cognitive processes involved in both the recollection and familiarity of episodic information (see also Moscovitch et al., 2005). For the purposes of this dissertation, I will focus on the elements of the model involved in the efficient encoding and subsequent recall of episodic memory. The extended hippocampal-diencephalic system involved in recollection was hypothesized to include medial temporal structures such as the hippocampus and fornix, as well as the mammilliary bodies and thalamic nuclei. Damage to any of the parts of this system would result in similar memory impairments (Aggleton & Brown, 1999; Moscovitch et al., 2005). Further, previous research has suggested a role for the prefrontal cortex as a "working-with-memory" structure that is involved in strategic components of memory retrieval (Aggleton & Brown, 1999; Moscovitch, 1992; Moscovitch et al., 2005; Moscovitch & Winocur, 2002). Damage to areas of the prefrontal cortex have been shown to be related to retrograde amnesia and confabulation (Gilboa, Alain, Stuss, Melo, Miller, & Moscovitch, 2006), suggesting that the prefrontal cortex may play a key role in monitoring memory retrieval (Moscovitch & Winocur, 2002).

Findings from Experiments 1 and 2 demonstrated that NA and NNA performance was significantly related to episodic memory. Combined with findings from Park et al. (2012) who showed an association between lesions to the thalamus and NNA crux accomplishment rates, I hypothesized that damage to any of the structures that are a part of the extended hippocampal-diencephalic system would be associated with poorer NA and NNA enactment performance, and related to episodic memory impairment.

Although NA and NNA crux and noncrux omission and commission error rates were not shown to be uniquely predicted by executive function in Experiment 1, it has been hypothesized that executive function, mediated by a distributed network of brain regions including the frontal lobes, may play an important role in NA (e.g. Luria, 1966; Schwartz et al., 1991) and NNA (Gold & Park, 2009) performance, particularly when attention was divided at encoding or at retrieval. Other studies by Zalla et al. (2001; 2003) showed that patients with prefrontal cortex damage had considerable difficulty segmenting action sequences into meaningful events. Similarly, Sirigu and colleagues (1995) investigated sequencing ability in patients with prefrontal and posterior (retrolandic) lesions and demonstrated that patients with prefrontal lobe damage were impaired in the sequencing of scripts of everyday actions (e.g., making coffee). Previous research has identified structures in the right hemisphere, specifically the right prefrontal sulcus and posterior regions such as the occipitotemporal cortex, as being activated during the segmentation of everyday activities (Zacks et al., 2001). Further, a study by Anderson et al. (2000) showed that dividing attention during encoding reduced memory performance and reduced activity in left-prefrontal and medial-temporal lobe regions.

Based on these findings, they proposed that dividing attention during encoding disrupted cognitive processes involved in efficient encoding of new stimuli into memory. In contrast, they found that dividing attention at retrieval did not impair memory performance or reduce retrieval-related brain activity, suggesting that dividing attention at retrieval does not interfere with cognitive processes required for efficient retrieval.

In summary, I hypothesized that damage to the prefrontal cortex, basal ganglia, as well as medial temporal lobe structures (e.g., hippocampus) and related structures (e.g., mamilliary bodies) that comprise the extended hippocampal-diencephalic system will result in impaired NNA performance.

Method

Participants.

Stroke participants. Twenty-seven participants from Stroke Groups 1 and 2 were included in this study. Neuroimaging results could not be obtained for 7 patients (Stroke Group 1: 102, 104, 105, 106, 109; Stroke Group 2: 312, 318).

Procedure.

Neuroimaging analysis. CT scans and 4 1.5T-MRI scans of stroke patients, acquired from several acute care centers in the Greater Toronto Area, were analyzed by a trained imaging analyst under the supervision of an experienced research radiologist and a neurologist.

Both radiological reports and clinical data about affected side were considered in order to identify all lesions. Since scans were acquired in an acute care setting, high resolution axial T1 images were not available for any patient. Slice thickness varied from

2.5 mm to 6 mm. Lesions were traced manually on axial slices of hybrid combined DWI-FLAIR coregistration for MR or a non-contrast CT scan.

After preprocessing, each scan was processed using a 2-D to 3-D protocol (Ferber & Danckert, 2006) to obtain a volume of DICOM images appropriate for coregistration to normalized stereotaxic template space. Scans were then co-registered to a high-quality composite image created from 27 scans of an individual created by the Montreal Neurological Institute (http://www.bic.mni.mcgill.ca/icbm:view), which were subsequently co-registered to the MNI305 template (http://imaging.mrc-cbu. cam.ac.uk/ imaging/MniTalairach). Coregistration was performed with Automated Image Registration using a linear 12-parameter affine transformation model to normalized template space (http://bishopw.loni.ucla.edu/AIR5). The resulting images had a voxel size of 1mm^3. Re-sliced images for each individual were visually inspected to ensure a high degree of correspondence to the template. Traced lesions were then re-sliced to normalized space, using the previously computed transformation matrix, and converted to region of interest files (ROIs) using the MRIcro software package (Karnath, Himmelbach, & Rorden, 2002). These ROIs were then converted to volume of interest files (VOIs) for analysis using the newer MRIcron software package (Rorden et al., 2007). A more detailed description of the procedure used to create standardized neuroimaging files is presented in Park et al., 2012.

Design. Separate voxel-wise analyses were performed for all enactment measures already described in Chapter 1. The Brunner-Munzel test (a non-parametric analog of the t-test) was used to obtain a non-parametric statistic testing for significant differences between patients with and without damage in each voxel (Rorden et al., 2007). Only voxels damaged in 10% or more individuals were included in analysis.

Results

Voxel-wise lesion analyses. Visual inspection of patient brain images revealed that most lesions were primarily localized to one hemisphere, and regions of damage varied across patients. Typically, when using MRIcron software, higher scores on behavioural measures indicate better performance. When lower scores are indicators of better performance, as in the case of omission and commission error rates, it is necessary to look at the negative z-scores. Thus, all templates display voxels with a Z-value lower than -1.65 which is associated with an uncorrected probability below .05. Uncorrected values may include a high number of false positives; however, it has been suggested that correction for multiple comparisons to a global false detection rate (FDR), similar to what is achieved with the Bonferroni correction, may be too conservative (Rorden, 2007). Consequently, real effects may not always be detected. Given small sample sizes, no data were found to achieve significance when FDR corrected. As such, z-scores reported below are uncorrected for FDR, and all findings should therefore be viewed as exploratory.

The NNA Learning Trials.

NNA Trial 1 analysis. Results of the voxel-wise analysis are presented in Figure 4.1. The top row demonstrates the distribution of lesions for all 27 patients included in the analysis. The influence of lesions on NNA Trial 1 enactment was investigated separately for each error rate measure (i.e., crux and noncrux omissions and commissions) and represented in subsequent rows.

Omission errors. It was observed that damage to the regions of the putamen and globus pallidus, which are primary components of the basal ganglia, as well as damage to mammillary bodies was associated with greater omission crux error rates. Z-scores ranged from – 1.65 to -2.70 corresponding to a probability range of .05 to .004.

Results indicate that higher omission noncrux error rates were primarily associated with damage to specific regions of the insula, putamen, and mammillary bodies. Z-scores ranged from -1.65 to -2.80 corresponding to a probability range of .05 to .003.

Commission errors. Findings from the voxel-wise analysis showed that greater crux commission error rates were primarily associated with damage to regions of the putamen, thalamus, and insula. Z-scores ranged from -1.65 to -2.44 corresponding to a probability range of .05 to .007.

Higher participant commission noncrux error rates were found to be associated with damage to regions of the insula in both the left and right hemispheres. Z-scores ranged from -1.65 to -2.45 corresponding to a probability range of .05 to .007.

Additional analyses for T2 and T3 are presented in Appendix K. Results indicate significant association between higher crux and noncrux omission and commission error rates and lesions in the putamen for both trials.

NA Performance. Results of the voxel-wise analysis are presented in Figure 4.2. The top row demonstrates the distribution of lesions for all 27 patients included in the analysis. The influence of lesions on NA enactment was investigated separately for each error rate measure (crux and noncrux omission and commission error rates) and represented in subsequent rows.

Omissions. Findings showed a significant association between greater stroke participant NA crux omission error rates and damage to regions of the basal ganglia (putamen and globus pallidus) as well as to the thalamus and claustrum. Z-scores ranged from -1.65 to -2.26 corresponding to a probability range of .05 to .01.

Similar findings were found for NA noncrux omission errors, where increased participant error rates were significantly associated with injury to areas of the basal ganglia (putamen and globus pallidus) as well as to the thalamus. Z-scores ranged from -1.65 to -2.24 corresponding to a probability range of .05 to .01.

Commissions. Results from the voxel-wise analysis indicated a significant association between greater NA crux and noncrux commission error rates and damage to areas of the putamen and thalamus. Maximum z-scores in these regions were -2.69, which corresponded to an uncorrected probability of .004.

The divided attention trials.

NNA performance when attention is divided at encoding (DF). Results of the voxel-wise analysis are presented in Figure 4.3. The top row demonstrates the distribution of lesions for all 16 patients included in the analysis. The influence of lesions on NNA enactment in the DF condition (i.e. attention divided at encoding) was investigated separately for each error rate measure (i.e., crux and noncrux omissions and commissions) and represented in subsequent rows.

Omission errors. Results of the voxel-wise analysis showed a significant association between a higher NNA crux omission error rate and damage to regions of the putamen. Maximum z-scores of -1.75 were shown in the thalamus, which corresponded to an uncorrected probability of .04.

Greater noncrux omission error rates in the DF condition were found to be significantly associated with injury to areas of the putamen and thalamus (ventral posterior lateral nucleus). Maximum z-scores of -2.13, analogous to an uncorrected probability of .02, were observed in lesions in these regions.

Commission errors. Interestingly, results indicated that higher NNA crux commission error rates in the DF condition were significantly correlated to damage in areas of the putamen, insula, and the left frontal lobe (precentral gyrus). Z-scores ranged from -1.65 to -2.36 corresponding to a probability range of .05 to .009.

Increased stroke patient noncrux commission error rate was observed to be significantly related to injury in the putamen and globus pallidus. Z-scores ranged from -1.65 to -2.24 corresponding to a probability range of .05 to .01.

NNA performance when attention is divided at retrieval (FD). Results of the voxel-wise analysis are presented in Figure 4.4. The top row demonstrates the distribution of lesions for all 16 patients included in the analysis. The influence of lesions on NNA enactment in the FD condition (i.e. attention divided at retrieval) was investigated separately for each error rate measure (i.e., crux and noncrux omissions and commissions) and represented in subsequent rows.

Omissions. Findings showed a significant association between greater stroke participant NNA crux omission error rates and damage to regions of the putamen and mammillary bodies (hypothalamus). Z-scores ranged from -1.65 to -2.15 corresponding to a probability range of .05 to .02.

Similar findings were found for NNA noncrux omission errors, where increased participant error rates were significantly associated with injury to areas of the lentiform nucleus (putamen and globus pallidus) as well as to the thalamus. Z-scores ranged from -1.65 to -2.12 corresponding to a probability range of .05 to .02.

Commissions. Findings showed a significant association between greater stroke participant NNA crux commission error rates in the FD condition and damage to regions of the putamen and insula. Z-scores ranged from -1.65 to -2.11 corresponding to a probability range of .05 to .02.

Findings from the voxel-wise analysis demonstrated that higher NNA noncrux commission error rates in the FD condition was associated with injury to areas of the frontal lobe (precentral gyrus and white matter tracks). A maximum z-score of -1.75 was observed which corresponds to an uncorrected probability of .04.

Relationship between total lesion size and NA and NNA enactment measures.

Table 4.1 shows the Pearson correlations between total lesion size and participant performance on NA and NNA enactment measures (i.e., omissions, commissions). No significant association was observed between total lesion size and NA and NNA crux and noncrux omission and commission error rates.

Figure 4.1. Top row shows overlap of 27 participant lesions. Bottom rows demonstrate results of voxel-wise analysis indicating areas with lesions that were significantly related to NNA T1 error rates. *Note*. Om. = Omission Error; Comm. = Commission Error.

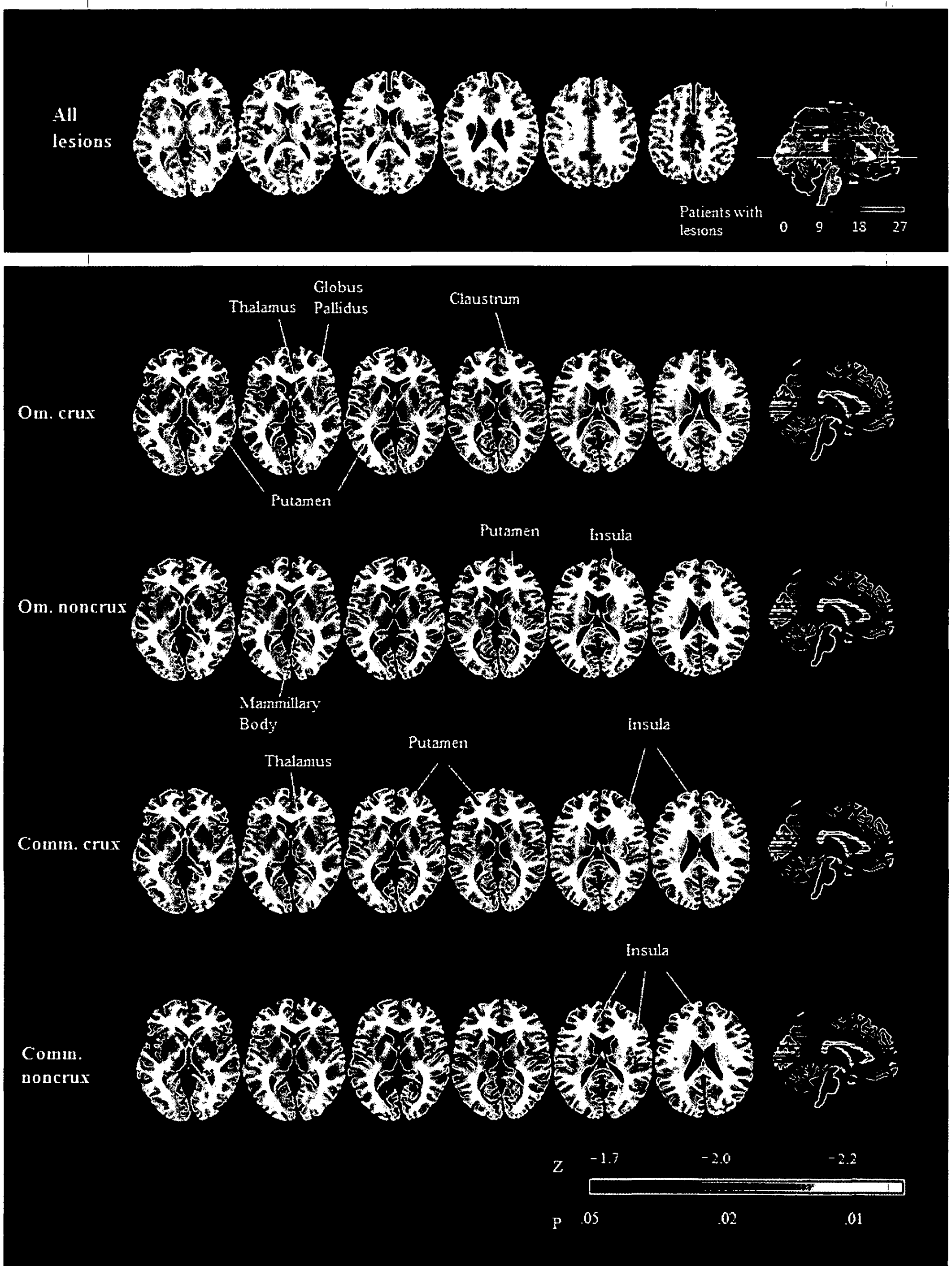


Figure 4.2. Top row shows overlap of 27 participant lesions. Bottom rows demonstrate results of voxel-wise analysis indicating areas with lesions that were significantly related to NA error rates. *Note.* Om. = Omission Error; Comm. = Commission Error.

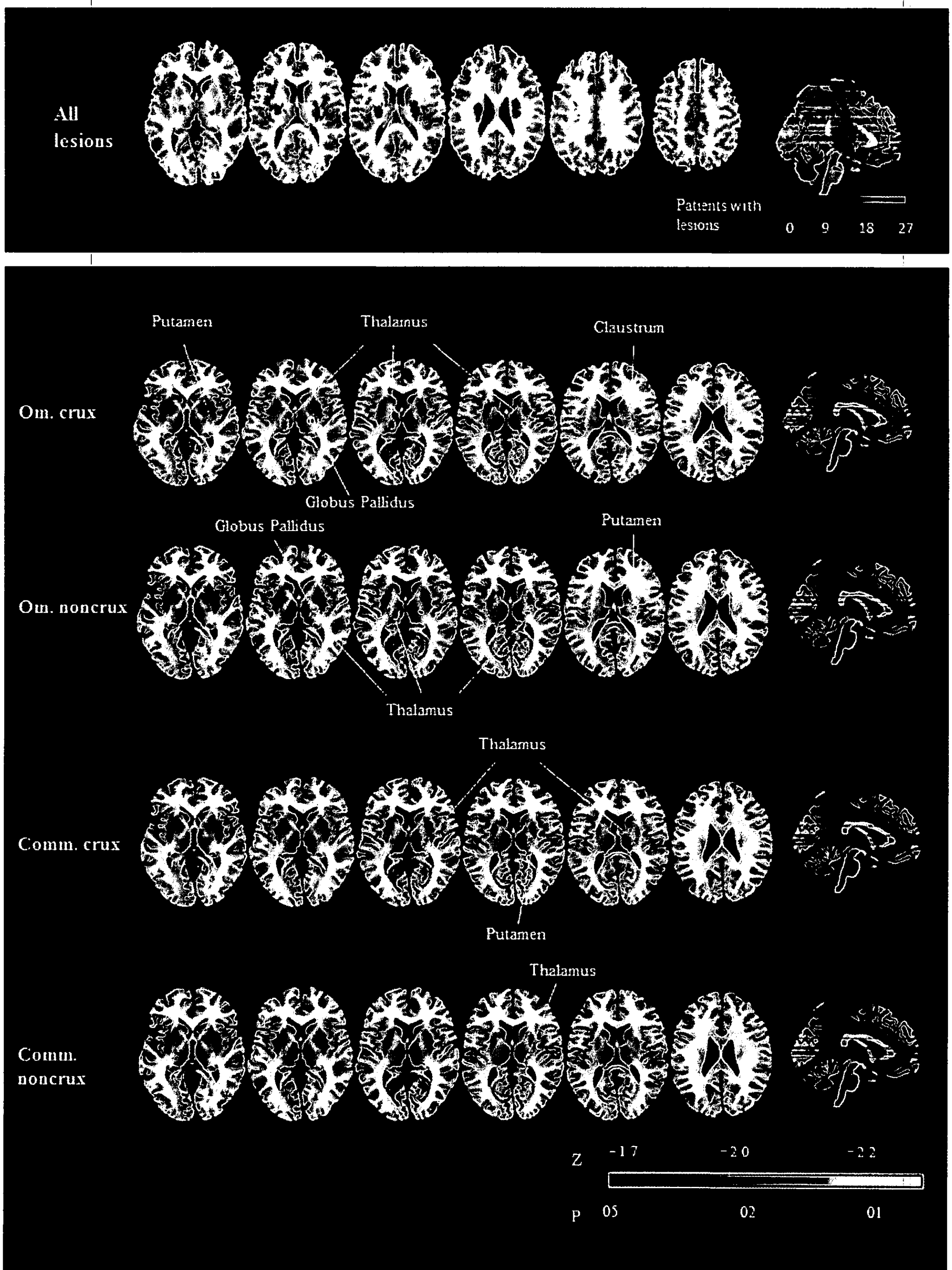


Figure 4.3. Top row shows overlap of 16 participant lesions. Bottom rows demonstrate results of voxel-wise analysis indicating areas with lesions that were significantly related to NNA error rates when attention was divided at encoding. *Note*. Om. = Omission Error; Comm. = Commission Error.

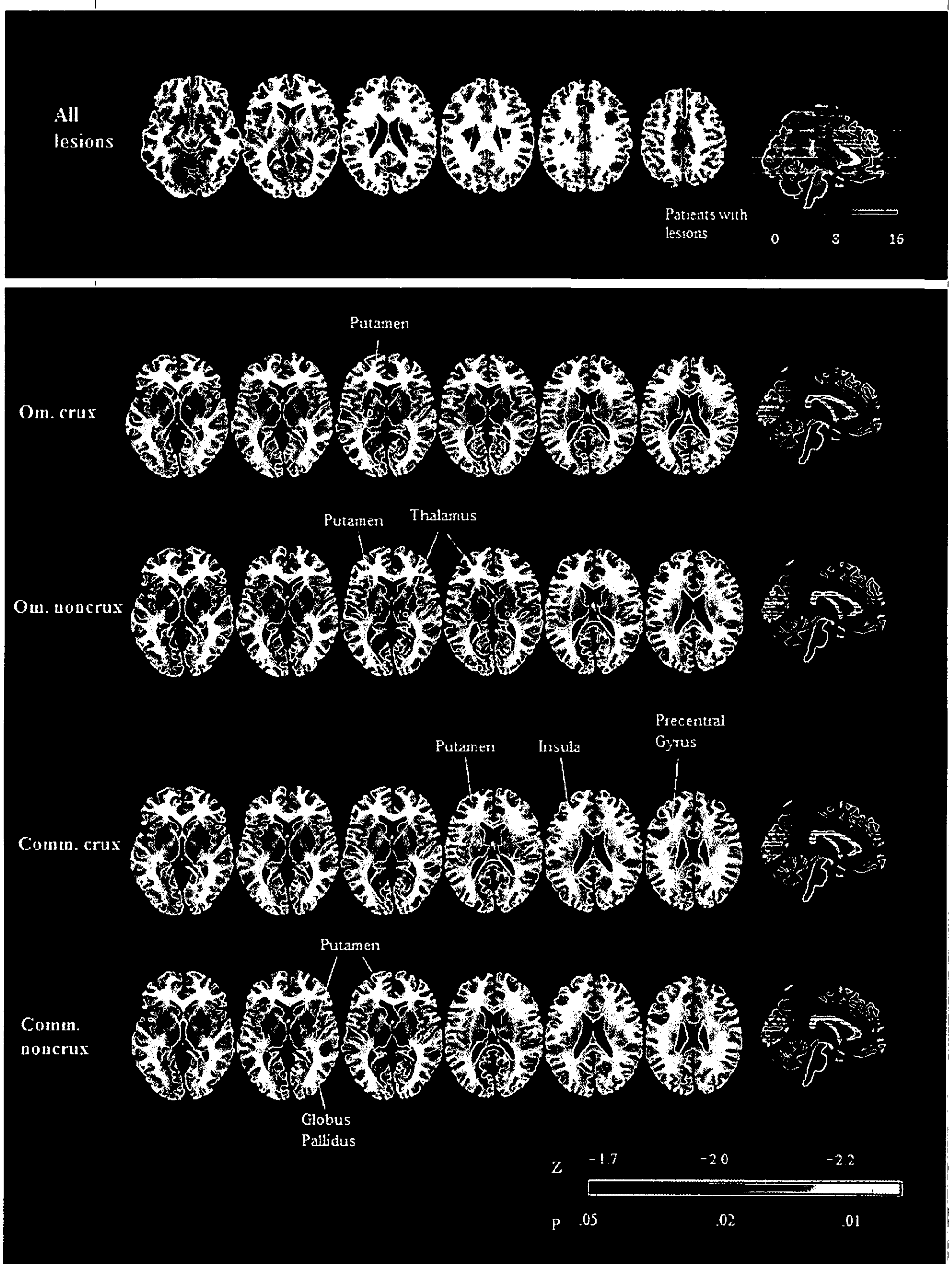


Figure 4.4. Top row shows overlap of 16 participant lesions. Bottom row demonstrate results of voxel-wise analysis indicating areas with lesions that were significantly related to NNA commission noncrux error rate. *Note.* Comm. = Commission Error.

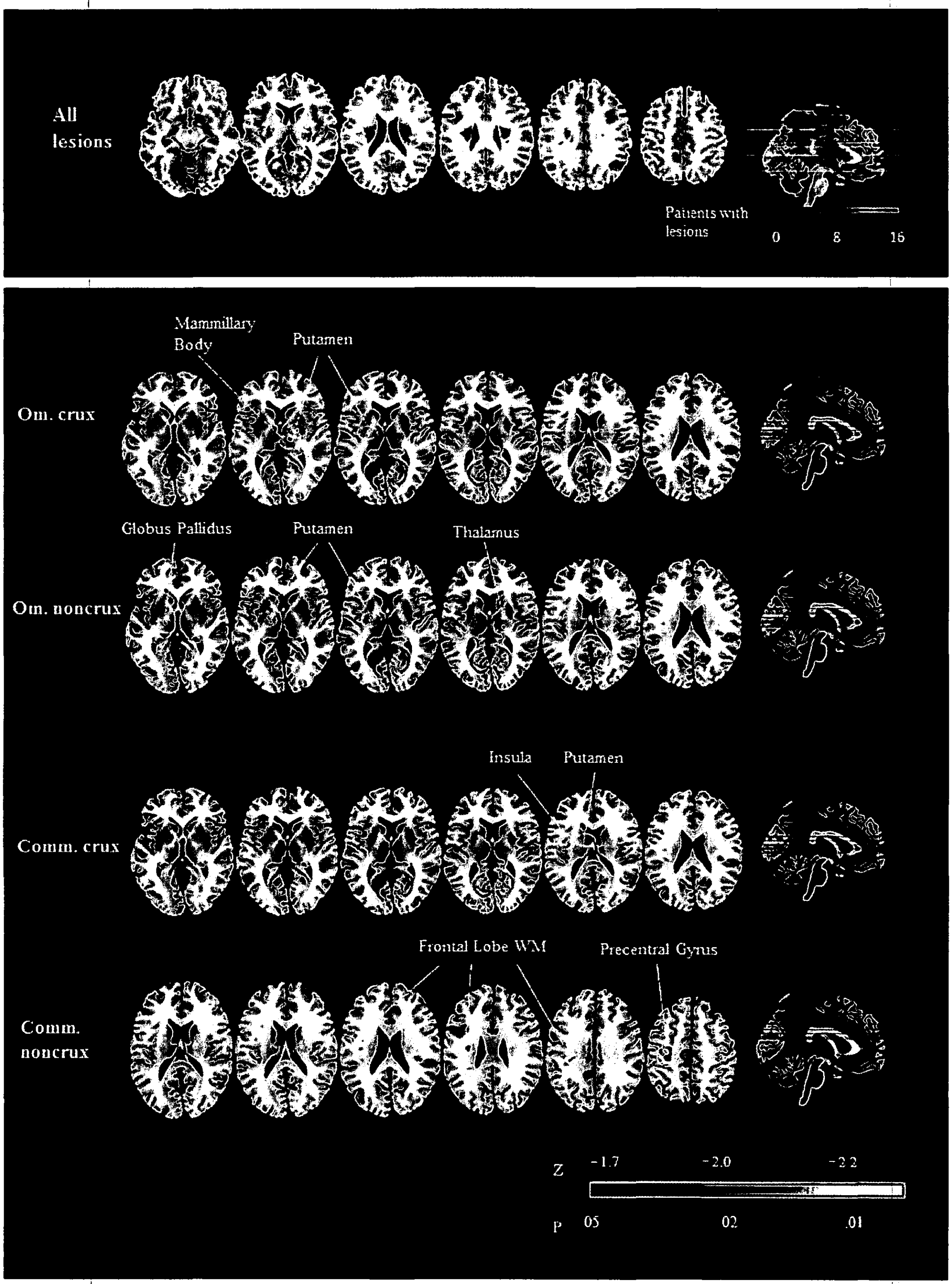


Table 4.1

Pearson Correlations between total lesion size and NA and NNA enactment measures

Measure	NA. Om. Crux	NA. Om. Noncrux.	NA.Comm. Crux	NA.Comm. Noncrux	NNA. Om. Crux	NNA. Om. Noncrux.	NNA.Comm. Crux	NNA.Comm. Noncrux
Total Lesion Size	.24	.17	-.18	-.08	-.01	.11	.05	-.05

Note. NA = Routine Naturalistic Actions; NNA = Novel Naturalistic Actions; Om. = Omission Error; Comm. = Commission Error.
$^{*}p \leq .05$, $^{**}p \leq .01$.

Discussion

General overview of findings. The aim of the present study was to examine whether lesions to specific neural regions were associated with NA and NNA error rates. The Bruner and Munzel test, a nonparametric analog to the t-test, was used to investigate whether NA and NNA error rates differed significantly between participants with and without damage for each voxel (Rorden et al., 2007). Due to small sample sizes, all reported findings should be viewed as exploratory.

Before proceeding to a discussion of the primary findings, it is worth noting that no significant correlation was found between total lesion size and NA and NNA enactment measures. This finding suggests that associations between specific voxels of damage and NA and NNA enactment measures were not solely dependent on total lesion size. Rather, the specific location of the lesion appears to play an important role in NA and NNA enactment performance. Historically, two alternative conceptualizations of NA and NNA impairment have been proposed. According to one view, impaired NA and NNA performance results from reduced general cognitive function (Giovannetti et al., 2002; Schwartz et al., 1998, 1999). More recently, it was proposed that specific cognitive processes located in particular neural regions are responsible for NA and NNA impairment (Giovannetti et al, 2008, 2012; Hartman & Goldenberg, 2005; Park et al., 2012). Findings from Experiment 3 provide support for the latter proposal.

The next section will discuss the neuroanatomical substrates that appear to play an important role in NA and NNA performance.

Neuroanatomical substrates of NA and NNA performance.

The thalamus, mammillary bodies, and memory. Lesions to the thalamus were shown to be strongly associated with increased NA and NNA error production in the current study. Although the thalamus is considered one of the most important sensory relay stations in the brain (Blumenfeld, 2002), it plays an important role in additional cognitive functions, particularly memory. Further, lesions to the mammilliary bodies were also shown to be associated with greater NNA error production. Previous studies have shown that damage to these structures has been related to memory loss, particularly in individuals with amnestic Korsakoff's syndrome (e.g., Kahn & Crosby, 1972; Vann & Aggleton, 2004). As outlined earlier, Aggleton and Brown (1999) proposed that the "extended hippocampal-diencephalic system" which includes anterior regions of the thalamus as well as diencephalic structures such as the mamilliary bodies, is involved in encoding of episodic information through its attribution of information with a spatial and temporal context.

The finding that damage to the extended hippocampal-diencephalic system resulted in impaired NA and NNA performance is consistent with behavioural data from Experiments 1 and 2. Results showed a strong relationship between participant scores on a composite measure of episodic memory and naturalistic action performance, especially with NAs. NNA performance was shown to be more strongly correlated with a measure of associative memory, which is a particular type of episodic memory. Taken together, the results of the current analysis suggest the involvement of episodic memory, mediated by the hippocampal-diencephalic regions is important in NA and NNA performance. Findings from this study are consistent with previous research that has shown a significant association between NA (Giovannetti et al., 2012) and NNA (Park et al., 2012) error rates and performance on episodic memory measures.

The basal ganglia and its related structures and procedural learning.

Findings from the current study demonstrated that lesions to basal ganglia structures including the putamen and globus pallidus were strongly associated with omission and commission error rates in both NAs and NNAs. Primarily, the basal ganglia have been shown to mediate the formation of stimulus-response associations or habits typically associated with a type of memory termed procedural learning (for a review, see Packard & Knowlton, 2002). This type of memory would include acquiring procedures, habits, as well as motor skill learning. Further, the basal ganglia have been shown to be dissociable from medial temporal lobe involvement, where patients with lesions to the basal ganglia were impaired on learning new procedural tasks, but showed unimpaired declarative memory for the task (Knowlton, Mangels, & Squire, 1996).

Interestingly, another region, the claustrum, was shown to play an important role in the production of NA and NNA errors, where lesions to the claustrum have been associated with poorer enactment performance. The claustrum has been long thought to be part of the basal ganglia (e.g., Heimer & Van Hoesen, 1979). Although the functions of the claustrum are not well defined, recent research in rats has proposed its role in interhemispheric communication aimed at bilateral coordination of regions of the primary motor cortex (Smith & Alloway, 2010). The claustrum has also been thought to be involved in multisensory integration. For example, when perceiving an object, numerous different stimuli across several modalities (i.e., color, shape, sound) would need to be integrated in order to perceive the object as a congruent and unified whole (Crick & Koch, 2005).

Findings from the current analysis, which consistently demonstrated the correlation between basal ganglia lesions and poorer NA and NNA performance, provide evidence that NAs and NNAs may be encoded both declaratively *and* procedurally. The role of the declarative and procedural memory systems in the acquisition of novel tools has been clearly demonstrated in a recent study which looked at how these two memory systems were involved in novel tool skill acquisition in a group of participants with Parkinson's disease (Roy, in preparation) as well as a case study of a participant with amnesia (Roy & Park, 2010). Individuals with Parkinson's disease normally exhibit damage to regions of a frontal-striatal network, including components of the basal ganglia, which, together are thought to be involved in motor-procedural learning (see Packard & Knowlton, 2002). In contrast, participants with amnesia have lesions to the extended hippocampal system and are impaired in encoding new information into long-term memory. Across these two studies, Roy and colleagues demonstrated a double dissociation in which individuals with Parkinson's disease were shown to be impaired on motor-procedural elements of the task (e.g., tool grasp, proper tool use), but unimpaired on measures of declarative memory. In contrast, the individual with amnesia was shown to be impaired on measures of declarative memory related to properties about the novel tools (i.e., tool color, identification of target object), but was unimpaired in his rate of learning of the motor-procedural elements of the task. Together, these results suggest a role for both the motor-procedural as well as the declarative memory system in learning novel tools.

With regard to NAs and NNAs, both types of actions require the use of tools such as pencils or scissors, and some of these tools are used in novel ways (i.e., poking a hole in a cup with a pencil). It can be argued that there are both procedural and declarative components to these tasks. NAs are familiar tasks that have been performed many times by the participant. Thus, in completing some components of the tasks such as putting the filter in the coffee machine or adding coffee grounds to the filter, participants may be relying on procedural memories for that action. In contrast, although NNAs are novel tasks that are not familiar to the participant, there may be action components within the tasks that rely on procedural memory. For example, in the ear guitar task, the participant must cut the string with the scissors. In this case, recall of motor skills, such as those involved in using scissors, would be necessary for the successful enactment of the NNA. In both NAs and NNAs, participants would rely on declarative knowledge (e.g., amount of coffee added, tool used to poke hole in cup) to successfully complete each task.

The frontal lobes and executive function. Finally, lesions to the frontal lobes were shown to be related to increased NA and NNA enactment error rates. This was particularly notable in the divided attention conditions, where participants had to either learn or enact a NNA while performing a secondary task. The frontal lobes are involved in several cognitive functions including executive functioning, which have been hypothesized to play a key role in the performance of NAs and NNAs (Giovannetti et al., 2012; Park et al., 2012). Specifically, the prefrontal cortex has been hypothesized to play a role in the generation of efficient encoding strategies which would, in turn, facilitate subsequent recall of learned information (Aggleton & Brown, 1999). Critical segmenting processes (i.e., breaking up action scripts into meaningful events), possibly involving projections between the right precentral sulcus and posterior occipitotemporal cortex, have been proposed to be engaged in the processing of naturalistic action (Zacks et al., 2001; Zalla et al., 2003). Novel naturalistic actions, which must first be viewed and encoded into memory in order to be subsequently enacted (retrieved), may draw upon executive processes involved in the segmentation and efficient encoding of viewed action. Taken together with results indicating a significant relationship between higher NA and NNA error rates and poorer participant performance on an executive function composite measure, the results from the current analysis provide additional substantiation for the role of the frontal lobes and more specifically, executive functioning, in the performance of naturalistic actions.

Summary. Overall, the findings from this study suggest a role for the declarative and motor-procedural memory systems as well as possible involvement of frontal regions in NA and NNA enactment performance. These results are consistent with findings from Experiments 1 and 2, where NA and NNA enactment was significantly correlated with participant performance on neuropsychological test measures of episodic and associative memory, which are types of declarative memory. In addition, both NA and NNA omission error rates were shown to be associated with participant performance on measures of executive function in both Experiments 1 and 2. Further, results from Experiment 3, proposing a role for the declarative and procedural memory system in the enactment of NAs and NNAs, are in keeping with what has been shown with a variety of different patient groups on goal-directed tasks using tools (e.g., Roy, in preparation). Like many behaviours, the cognitive network involved in learning and performing NAs and NNAs is probably quite complicated. The findings from this experiment, in addition to results from Experiments 1 and 2, suggest that several cognitive processes including episodic memory, associative memory, and executive function are involved in the encoding and subsequent enactment of naturalistic actions.

Chapter 5: General Discussion

The relative role of episodic memory, associative memory, executive function, and motor-procedural learning in NA and NNA performance

The purpose of this dissertation was to investigate the cognitive and neural processes associated with the performance of NAs and NNAs, in a sample of participants with stroke compared to a group of age- and education-matched controls. Overall, the results from my study provide a strong argument for the role of episodic and associative memory in learning and performing new tasks as well as in the enactment of familiar actions that have been performed many times. However, the role of executive function in NA and NNA enactment performance was not clearly established.

In Experiment 1, higher scores on episodic memory and executive function measures were correlated with fewer action omissions for NAs and NNAs, consistent with findings from Experiment 2 as well as with previous research (Park et al., 2012). Further, in the case of NNAs, but not NAs, there was also a strong association between higher crux and noncrux omission error rates and lower scores on a measure of associative memory. In contrast, in Experiment 2, commission crux error rates were shown to be correlated with associative memory scores in the FF condition. Findings from Experiment 2 are generally consistent with results from Park et al. (2012), which showed a relation between associative memory measures and NNA crux and noncrux commission error rates. This variability in performance patterns between Experiments 1 and 2 may be attributed to a key design difference between the two studies. Namely, in Experiment 1, participants were instructed to enact four NNAs, three times each. In contrast, in Experiment 2, participants were required to enact only one NNA for each attention condition, possibly reducing sensitivity of the behavioural measures.

Results from Experiment 1 were further explored in a hierarchical regression analysis which indicated that with NNAs, associative memory uniquely predicted NNA crux and noncrux omission error rates. In contrast, for NAs, episodic memory uniquely predicted crux and noncrux omission error rates. Thus, although episodic memory, associative memory, and executive function measures have been shown to be correlated with both the enactment of NAs and NNAs, it would appear that associative memory may play a more important role in NNA performance, whereas episodic memory may play a more key role in NA performance. Executive function did not significantly predict NA and NNA enactment performance.

Neuroimaging findings from Experiment 3 provide further support for the hypothesis that episodic and associative memory are involved in the performance of NAs and NNAs. For NAs and NNAs, damage to similar brain regions was negatively associated with task performance. Specifically, these brain regions include components of the "extended hippocampal–diencephalic system" which is widely believed to be involved in the recollection of episodic memory (e.g., Aggleton & Brown, 1999; Moscovitch et al., 2005). Findings from Experiment 3 also suggest that structures of the basal ganglia (e.g., putamen and globus pallidus) may also be associated with NA and NNA performance. These structures have been implicated in motor-procedural learning (see Packard & Knowlton, 2002). Thus, there is strong support for the hypothesis that both declarative and motor-procedural memory systems may be involved in NA and NNA enactment. This finding is consistent with previous research with novel tools (Roy, in preparation) and has been discussed in previous research which examined NNA performance in a subset of the participants with stroke used in this study (Park et al., 2012).

Although neuroimaging findings are consistent with the hypothesis that declarative and motor-procedural memory are involved in the enactment of NAs and NNAs, the role of executive function in NNA performance was unclear. An association was demonstrated between higher commission error rates and frontal lesions, particularly in divided attention conditions. This finding is consistent with previous research with NAs that showed a role of executive function in commission error rate (Bettcher et al., 2008; Giovannetti, et al., 2012; Kessler et al., 2007). However, the relationship between performance on executive function measures and NNA enactment was not supported by behavioural data from Experiments 1 and 2. One of the reasons that a stronger association between executive function and NA and NNA enactment was not demonstrated may lie in the nature of the executive function composite measure. As this measure is comprised of different tests of executive function (i.e., switching attention, inhibition, generation, planning), subtle differences in performance in each of these cognitive domains and the subsequent correlation with NNA error rates would have been weakened within the combined score. In this way, the executive function composite may not have been a sensitive enough measure of "executive functioning".

In summary, behavioural and neuroimaging findings from Experiments 1, 2, and, 3 strongly suggest a role for episodic memory, associative memory as well as motor-procedural memory in both NA and NNA performance. Neuroimaging results in Experiment 3 may indicate a role of executive function in NNA divided attention conditions.

Neuropsychological components of episodic and associative memory measures

In this dissertation, there was a strong association between episodic memory measures and NA and NNA performance. Similar findings are reported by other investigators of NAs who showed a relationship between episodic memory measures and NA omission error rates (Giovannetti et al., 2008; 2012). Although these empirical findings are robust, use of the term "episodic memory" and its interpretation are problematic for a few reasons. First, as previously mentioned, the usage of the term "episodic memory" in the current study refers to recall of previously presented material. Although the usage of this term is consistent with the definition of episodic memory used in past research with naturalistic actions (Giovannetti et al., 2008; 2012; Park et al., 2012), it differs from other investigators who define episodic memory as memory for autobiographical events (i.e., Tulving, 1972). Second, it is unclear why measures such as the HVLT-R, generally believed to be a measure of newly acquired material (i.e., episodic memory), should be associated with NA performance, a type of semantic memory. One possible resolution of this dilemma was suggested by Giovannetti et al. (2012) who suggested that the episodic memory measures used in her studies (as well as those used in Park et al., 2012 and the current study) may be indicative of degraded task knowledge (i.e., semantic knowledge of everyday tasks). This interpretation is puzzling because the HVLT-R and other measures of episodic memory are generally believed to measure episodic and not semantic memory. However, previous research has shown that on a multiple trial word-list measures similar to the HVLT-R, participants who showed better memory for the word-lists presented were able to better structure and organize the information presented (e.g., Bower, 1970; Farrell, 2012; Tulving, 1962). Further, the BVMT-R, a multiple trial, visual memory measure has been shown to be correlated with semantic memory measures including the Boston Naming Test (Benedict et al., 1996). Thus, neuropsychological measures such as the HVLT-R and BVMT-R, which are often conceptualized as "episodic memory" measures, may comprise both episodic and semantic components. In other words, measures such as the HVLT-R and BVMT-R may tap both episodic and semantic memory.

In addition, it can be hypothesized that associative memory, which is defined as memory for relationships among items of information, may also have both episodic and semantic components. For example, although NNAs are novel tasks that have not been performed prior to being viewed, they are not bizarre. Thus, components of the task requiring the formation of associations between objects and actions may involve semantic and episodic memory in the efficient encoding and retrieval of NNAs. For instance, in the ear guitar task, a subject is required to measure and cut a piece of string. Remembering to cut the string with scissors (necessitating the formation of an association between string, scissors and the act of cutting) may draw upon semantic knowledge that a scissor is used for cutting. In contrast, more detailed associations that are unique to the task at hand, such as remembering that the actor measured two ruler lengths before cutting the string (requiring the formation of an association between ruler, string, and measuring by overlapping string against ruler), may necessitate drawing upon episodic memory of what the participant saw the actor do in the video. In summary, both semantic and episodic memory are likely involved in performing NAs and NNAs. However, the degree to which episodic and semantic memory are involved in participant performance on episodic and associative memory measures and their association to NA and NNA performance has not yet been clearly defined.

Implications of NA versus Trial 1 (T1) NNA performance in participants with stroke

Generally participants with stroke accomplished fewer actions and made more errors during the enactment of NAs and NNAs when compared to control participants. This is consistent with previous studies that showed that participants with either LHD or RHD were impaired in the enactment of NAs (e.g., Buxbaum et al., 1998; Schwartz et al., 1999) and NNAs (Park et al., 2012). Unexpectedly, participants with stroke accomplished more actions and produced fewer errors on T1 NNA performance compared to NAs. In contrast, controls performed better during the enactment of NAs compared to NNAs.

Better T1 NNA than NA performance in participants with stroke was unexpected. However, as previously reported, participants with stroke were recruited from a rehabilitation hospital, where it was likely they had not been participating in functional activities of daily living such as cooking for an extended period of time. As a result, it is possible that the lack of opportunity to complete these tasks on a regular basis contributed to degraded task knowledge for goal-directed, multistep actions such as making a cup of coffee using a coffee-maker. In contrast, better T1 NNA performance may be attributable to recent viewing of the NNA. If these findings are replicated in future research, they may have implications for stroke rehabilitation as well as for the treatment of individuals living in an assisted-living facility. Specifically, these findings suggest a need for continual engagement in activities of daily living (whenever possible) so as to prevent a decline in functionality.

Limitations and Future Directions

One of the limitations of this study is that it is not possible to directly evaluate the degree to which NA and NNA task knowledge is degraded in either participants with stroke or controls. Thus, although it has been proposed that the pattern of poorer performance on NAs compared to NNAs in participants with stroke was possibly due to degraded task knowledge resulting from a lack of practice of everyday activities, the degree to which task knowledge (or lack thereof) was responsible for impaired NA enactment performance could not be assessed. This limitation could be addressed in two distinct ways. First, it would be useful to determine how frequently NAs were performed in the period of time following the stroke up until their participation in the study. Second, it would be helpful to assess NA performance of stroke patients, and then determine whether NA performance improved after participants were shown a video of the NA performed.

Future studies could also include an objective measure of task knowledge, directed at assessing both semantic and episodic components of the specific NAs and NNAs presented. In this way, NA and NNA enactment could be evaluated in relation to task knowledge, where it might be possible to better determine which elements of each task are more vulnerable to decay. For example, participants could be asked to sequence photos depicting the major steps of each task in an order that would result in the proper completion of each action. Performance on an objective measure of task knowledge could be examined with respect to episodic memory scores to better evaluate the hypothesis that episodic memory failures, as measured by episodic memory tasks, are indicative of degraded task knowledge (Giovannetti et al., 2012). If this is the case, it would be expected that a strong relationship between measures of task knowledge and episodic memory would be observed. In addition, it can be hypothesized that if episodic memory failure is indicative of task knowledge, then an analysis of the influence of lesions on performance of measures of task knowledge might demonstrate that structures in the brain related to episodic memory such as those comprising the extended hippocampal-diencephalic system (e.g., thalamus, mammillary bodies) are significantly correlated to poorer performance on measures of task knowledge. It might also be important to look at task knowledge with respect to duration of stay in the rehabilitation hospital in order to further investigate the slope of task knowledge decay with respect to time.

Second, there was only one measure of associative memory used in this study which assessed how well participants remembered relationships between items and their location. In order to increase sensitivity for differences in associative memory functioning between groups, future studies should include a composite measure comprised of additional tests of associative memory (e.g., verbal pairs, names and faces). In this way, the sensitivity and construct validity of the associative memory measure and its consequent impact on NA and NNA performance could be examined more thoroughly.

Third, the executive function composite may not have been a sensitive enough measure. The term "executive function" is an umbrella term which denotes multiple cognitive processes that control or regulate other cognitive processes such as initiation, problem solving, inhibition, planning and organization. Thus, due to the fractionation of executive functions and their relative contributions to NA and NNA performance, the executive function composite which comprised tests measuring multiple cognitive domains, may not have assessed the cognitive functions required to perform NAs and NNAs. Future studies could look at creating different executive function composite measures each comprised of multiple neuropsychological tests that are representative of a similar cognitive domain (e.g., problem solving). Thus, the role of specific executive functions in NA and NNA enactment performance could be more thoroughly investigated.

Finally, sample sizes of the participant groups for each experiment were relatively small, subsequently resulting in diminished power. Thus, analyses looking at the influence of lesions on NA and NNA omission and commission error rates were performed with all stroke patients in order to increase power. Small sample sizes precluded investigations into the effects of laterality on NA and NNA performance as that would have required that stroke participant groups be subdivided into subjects with either LHD or RHD for each experiment, thereby, further reducing group sizes. Previous findings (Lombardi, 2007) suggested that although participants with LHD and RHD were both impaired on NA and NNA enactment, they appeared to be impaired for different reasons. Specifically, results from that study indicate a role of the left hemisphere in tool-action knowledge and suggest a possible role of the right hemisphere in the representation (and possible sequencing) of multistep actions (see also Hartman & Goldenberg, 2005). Thus, future studies with a greater number of participants could examine the influence of lesions on NA and NNA enactment measures by hemisphere. In this way, the effects of laterality on NA and NNA performance could be better investigated.

Conclusions

This study investigated the neuropsychological processes involved in NA and NNA performance, with the aim of developing a clearer understanding of the cognitive processes underlying goal-directed, multistep action. Overall, behavioural and neuroimaging data from Experiments 1, 2, and 3 showed that declarative memory (i.e., episodic and associative memory) and motor-procedural memory are involved in NA and

NNA enactment. Thus, results from this study indicate that both NAs and NNAs require motor-procedural and declarative memory processes; however, they differ in the relative involvement of different types of declarative memory systems. The current findings suggest a unique role of associative memory for NNAs compared to NAs, where successful NNA enactment is critically dependent on the formation of new associations between object, target, and action. In contrast, results indicate that episodic memory may play a greater role in NA than NNA performance, where episodic memory failures may be indicative of degraded task knowledge. The role of executive function in NA and NNA enactment was not consistent across experiments, but neuroimaging data from Experiment 3 suggest a role of executive function in NNA commission error rates, particularly under divided attention conditions. Taken together, this study provides further support that NAs and NNAs share overlapping processes, but that there may be unique cognitive contributions to each task.

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Appendix A

PRE-SCREEN QUESTIONAIRE – Form 01

PERSONAL INFORMATION

Participants Name:	**Age:**	**Gender:** F ☐ M ☐	**Date:**
Participants Number:	**Date of Birth:**	**Country of Birth:**	
Total years of Education:	Occupation:		

Is English you native language? YES ☐ NO ☐ ⇩	What other languages do you speak? Language:	Language:
If NOT, how would you rate your fluency? Not fluent at all 1 2 3 4 5 6 7 perfectly fluent	Fluency Not fluent at all 1 2 3 4 5 6 7 perfectly fluent	Fluency Not fluent at all 1 2 3 4 5 6 7 perfectly fluent
At which age you began to speak English on a regular basis?	Age learned	Age learned
Handedness: R ☐ L ☐	What hand do you pick up objects with? R ☐ L ☐	What hand do you write with? R ☐ L ☐
Do you have difficulty grasping and/or manipulating objects? YES ☐ NO ☐	Are you color blind? YES ☐ NO ☐	Do you have any problems learning? YES ☐ NO ☐

MEDICAL HISTORY - Have you ever had…?

Stroke? YES ☐ NO ☐	Heart Attack? YES ☐ NO ☐	Brain surgery? YES ☐ NO ☐	Seizures? YES ☐ NO ☐	Chemotherapy? YES ☐ NO ☐	Diabetes? YES ☐ NO ☐
Neurological Disorder? (MS, PD, HD, CP, AD) YES ☐ NO ☐		Encephalitis or meningitis? YES ☐ NO ☐		Thyroid? YES ☐ NO ☐	Trouble Sleeping? YES ☐ NO ☐

Have you ever been diagnosed with any mental disorder such as depression and/or anxiety? YES ☐ NO ☐	If so, please describe which disorder and when you were diagnosed:
Do you currently have ANY medical conditions? YES ☐ NO ☐	If so, please describe which medical conditions you are currently experiencing?
Are you currently taking any regular medication? YES ☐ NO ☐	If so, please specify medication and purpose:

Are there any other medical conditions you would like to tell us about?

Have you ever sustained a serious head injury? YES ☐ NO ☐	If yes, at what age?	Did it result in unconsciousness? YES ☐ NO ☐
Did you experience memory loss? YES ☐ NO ☐	If yes, for how long?	

SUBSTANCE USE

Do you drink alcohol? YES ☐ NO ☐	Have you ever drunk so much you lost consciousness? YES ☐ NO ☐	Do you smoke? YES ☐ NO ☐
If yes, how much?	If Yes, how many times?	How many per day?
Have you ever taken any illegal substances? YES ☐ NO ☐	If yes, how many times? YES ☐ NO ☐	If yes, have you ever have an overdose? YES ☐ NO ☐

Appendix B

Participant Name___________________
Date___________________
Name of Tester___________________

Sending a Card

1) Have you ever sent a card, letter or paid a bill by mail?

No ☐ If you answered **No** to the above question proceed to **next page.**

Yes ☐ If you answered **Yes** to the above question proceed to **question 2.**

2) How many times in the past week did you send a card, letter or pay a bill by mail?

Not at all ☐ **1-2 times** ☐
3-5 times ☐ **More than 5 times** ☐

3) How many times in the past month did you send a card, letter or pay a bill by mail?

Not at all ☐ **1-2 times** ☐
3-5 times ☐ **More than 5 times** ☐

4) About how many times have you sent a card, letter or paid a bill by mail in a typical year?

Not at all ☐ **Less than 10 times** ☐
Less than 20 times ☐ **More than 20 times** ☐

5) When was the last typical year that you sent a card, letter, or paid a bill?

0 – 1 years ago ☐ **2-5 years ago** ☐

6-10 years ago ☐ **More than 10 years** ☐

6) For about how many years have you sent a card, letter or paid a bill by mail?

_______ years

Participant Name____________________

Date____________________

Name of Tester____________________

Birdfeeder

1) Have you ever made a birdfeeder using arts and crafts materials such as birdseed and glue?

No ☐ If you answered <u>**No**</u> to the above question proceed to **<u>next page.</u>**

Yes ☐ If you answered <u>**Yes**</u> to the above question proceed to **<u>question 2.</u>**

2) How many times in the past week have you made a birdfeeder?

Not at all ☐
1-2 times ☐
3-5 times ☐
More than 5 times ☐

3) About how many times have you done this in the past year?

Number of times ____________

Appendix C

Modified Action Coding System Scripts
Note. Crux actions are bolded, noncrux actions are in plain text

NA: Making Coffee
Expected Tasks:
TAKE (coffee machine)
MOVE (coffee machine) TO (in front of agent) VIA (hand) BY (sliding)
GIVE (coffee machine)
TAKE (coffee pot)
MOVE (coffee pot) TO (in front of agent) VIA (hand) BY (lifting)
GIVE (coffee pot)
TAKE (coffee pot lid)
ALTER (coffee pot) TO (coffee pot with lid open) VIA (hand) BY (opening lid)
GIVE (coffee pot lid)
TAKE (water bottle)
TAKE (water bottle cap)
ALTER (water bottle) TO (water bottle without cap) VIA (hand) by (unscrewing cap)
MOVE (cap) TO (on table beside agent) VIA (hand) BY (lifting and lowering)
GIVE (cap)
MOVE (water bottle) TO (towards coffee pot) VIA (hand) BY (lifting)
ALTER (coffee pot) TO (coffee pot filled with water) VIA (water bottle) BY (pouring water into pot)
MOVE (water bottle) TO (away from coffee pot) VIA (hand) BY (lowering)
TAKE (water bottle cap)
MOVE (cap) TO (bottle) VIA (hand) BY (lifting)
ALTER (bottle) TO (bottle with cap) VIA (hand) by (screwing on cap)
MOVE (water bottle) TO (on table beside agent) VIA (hand) BY (lifting and lowering)
GIVE (water bottle)
TAKE (coffee pot lid)
ALTER (coffee pot) TO (coffee pot with closed lid) VIA (hand) BY (lowering pot lid)
GIVE (coffee pot lid)
TAKE (coffee machine water chamber lid)
ALTER (coffee machine) TO (coffee machine with water chamber open) VIA (hand) BY (raising coffee machine water chamber lid)
GIVE (coffee machine water chamber lid)

TAKE (coffee pot)
MOVE (coffee pot) TO (coffee machine water chamber) VIA (hand) BY (lifting)
ALTER (coffee machine water chamber) TO (coffee machine water chamber filled with approx 2 cups of water) VIA (filled coffee pot) BY (pouring)
MOVE (coffee pot) TO (into coffee machine) VIA (hand) BY (lifting)
GIVE (coffee pot)
TAKE (coffee machine water chamber lid)
ALTER (coffee machine) TO (coffee machine with closed water chamber lid) VIA (hand) BY (lowering lid)
GIVE (coffee machine water chamber lid)
TAKE (coffee machine coffee chamber)
ALTER (coffee machine) TO (coffee machine with open coffee chamber) VIA (hand) BY (swinging open coffee machine coffee chamber)
GIVE (coffee machine coffee chamber)
TAKE (coffee filter)
MOVE (coffee filter) TO (coffee machine coffee chamber) VIA (hand) BY (lifting)
ALTER (coffee machine coffee chamber) TO (coffee machine coffee chamber with coffee filter inside) VIA (coffee filter) BY (putting coffee filter inside coffee machine coffee chamber)
GIVE (coffee filter)
TAKE (coffee container)
MOVE (coffee container) TO (in front of agent) VIA (hands) BY (sliding)
ALTER (coffee container) TO (open) VIA (hand) BY (removing coffee container lid)
TAKE (coffee container lid)
MOVE (coffee container lid) TO (on table beside agent) VIA (hand) BY (lifting)
GIVE (coffee container lid)
TAKE (scoop)
MOVE (scoop) TO (coffee container) VIA (hand) BY (lifting)
ALTER (scoop) TO (scoop filled with coffee) VIA (coffee container) BY (scooping coffee out of coffee container)
MOVE (filled scoop) TO (coffee machine coffee chamber) VIA (hand) BY (lifting)
ALTER (coffee machine coffee chamber) TO (coffee machine coffee chamber filled with coffee) BY (dumping scoop into coffee machine coffee chamber)
MOVE (scoop) TO (coffee container) VIA (hand) BY (lifting)
ALTER (scoop) TO (scoop filled with coffee) VIA (coffee container) BY (scooping coffee out of coffee container)
MOVE (filled scoop) TO (coffee machine coffee chamber) VIA (hand) BY (lifting)

ALTER (coffee machine coffee chamber) TO (coffee machine coffee chamber filled with more coffee) BY (dumping scoop into coffee machine coffee chamber)
MOVE (scoop) TO (coffee container) VIA (hand) BY (lifting)
ALTER (scoop) TO (scoop filled with coffee) VIA (coffee container) BY (scooping coffee out of coffee container)
MOVE (filled scoop) TO (coffee machine coffee chamber) VIA (hand) BY (lifting)
ALTER (coffee machine coffee chamber) TO (coffee machine coffee chamber filled with more coffee) BY (dumping scoop into coffee machine coffee chamber)
MOVE (scoop) TO (on table beside agent) VIA (hand) BY (lowering)
GIVE (scoop)
TAKE (coffee container lid)
ALTER (coffee container) TO (closed coffee container) VIA (coffee container lid) BY (putting on coffee container lid)
GIVE (lid)
GIVE (coffee container)
TAKE (coffee machine coffee chamber)
ALTER (coffee machine) TO (coffee machine with closed coffee machine coffee chamber) VIA (hand) BY (swinging coffee machine coffee chamber closed)
GIVE (coffee machine coffee chamber)

NA: Preparing a Card to be Mailed
Expected Tasks:
TAKE (card)
MOVE (card) TO (on table in front of agent) VIA (hand) BY (sliding)
GIVE (card)
TAKE (pen)
MOVE (pen) TO (in front of agent) VIA (hands) BY (lifting)
TAKE (pen cap)
ALTER (pen) TO (pen without cap) VIA (hand) BY (removing pen cap)
MOVE (pen cap) TO (away from agent) VIA (hand) BY (lifting and lowering)
GIVE (pen cap)

TAKE (card)
ALTER (card) TO (unfolded) VIA (hand) BY (unfolding card)
MOVE (pen) TO (towards card) VIA (hand) BY (lifting and lowering)
ALTER (card) TO (card with info and signature) VIA (pen) BY (writing info and signing card)
GIVE (card)
TAKE (pen cap)
MOVE (pen cap) TO (pen) VIA(hand) BY(lifting)
ALTER (pen) TO (closed) VIA (pen cap) BY (pushing on pen cap)
GIVE (pen cap)
MOVE (pen) TO (away from agent) VIA (hand) BY (lowering)
GIVE (pen)
TAKE (card)
ALTER (card) TO (folded) VIA (hand) BY (folding card)
TAKE (envelope)
MOVE (envelope) TO (on table in front of agent) VIA (hand) BY (lifting)
ALTER (envelope) TO (envelope with card inside) VIA (hand) BY (inserting card into envelope)
GIVE (card)
MOVE (envelope) TO (mouth of agent) VIA (hand) BY (lifting)
ALTER (envelope) TO (prepared) VIA (tongue) BY (licking envelope)
TAKE (wet sponge)
MOVE (wet sponge) TO (on table in front of agent) VIA (hand) BY (sliding)
GIVE (wet sponge)
ALTER (envelope) TO (prepared) VIA (wet sponge) BY (wetting finger and dampening glue seal)
ALTER (envelope) TO (sealed) VIA (hand) BY (closing envelope flap and pressing down)
TAKE (wet sponge)

MOVE (wet sponge) TO (away from agent) VIA (hand) BY (sliding or lifting)
GIVE (wet sponge)
MOVE (envelope) TO (inverted) VIA (hand) BY (turning so that envelope face is upward).
GIVE (envelope)
TAKE (“to” label sheet)
MOVE (“to” label sheet) TO (in front of agent) VIA (hand) BY (lifting)
TAKE ("to" label)
ALTER (“to” label sheet) TO (“to” label sheet minus one “to” label) VIA (hand) BY (removing one “to” label)
MOVE (“to” label sheet) TO (table) VIA (hand) BY (lifting and lowering)
GIVE (“to” label sheet)
MOVE ("to" label) TO (towards envelope) VIA (hand) BY (lifting and lowering)
ALTER (envelope) TO (envelope with “to” label) VIA (“to” label) BY (sticking “to” label onto envelope)
GIVE ("to" label)
TAKE (“from” label sheet)
MOVE (“from” label sheet) TO (in front of agent) VIA (hand) BY (lifting)
TAKE ("from" label)
ALTER (“from” label sheet) TO (“from” label sheet minus one “from” label) VIA (hand) BY (removing one “from” label)
MOVE (“from” label sheet) TO (table) VIA (hand) BY (lowering)
GIVE (“from” label sheet)
MOVE ("from" label) TO (towards envelope) VIA (hand) BY (lifting and lowering)
ALTER (envelope) TO (envelope with “from” label) VIA (“from” label) BY (sticking “from” label onto envelope)
GIVE ("from" label)

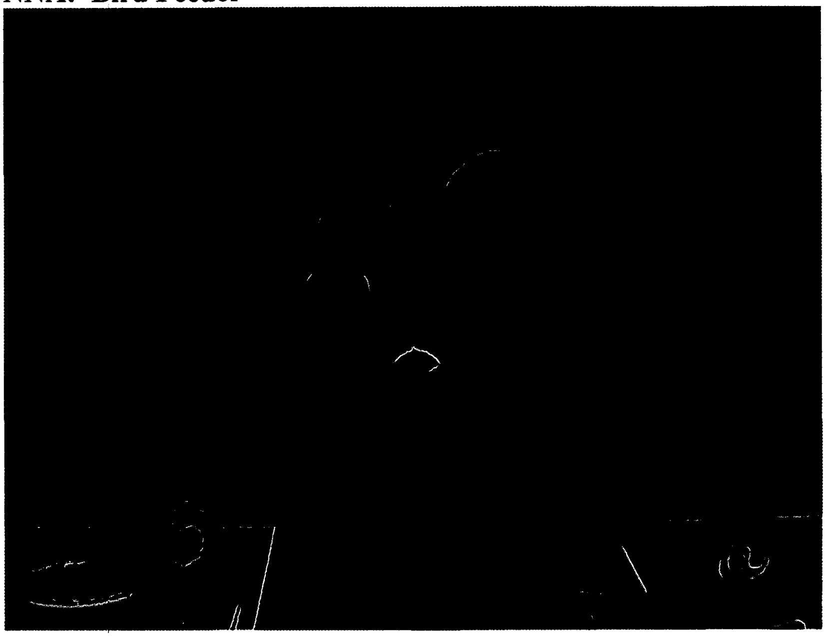
TAKE (stamp sheet)
MOVE (stamp sheet) TO (in front of agent) VIA (hand) BY (lifting)
TAKE (stamp)
ALTER (stamp sheet) TO (stamp sheet minus one stamp) VIA (hand) BY (removing one stamp)
MOVE (stamp sheet) TO (table) VIA (hand) BY (lowering)
GIVE (stamp sheet)
MOVE (stamp) TO (towards envelope) VIA (hand) BY (lifting and lowering)
ALTER (envelope) TO (envelope with stamp) VIA (stamp) BY (sticking stamp onto envelope)
GIVE (stamp)
GIVE (envelope)

NA: Sandwich
Expected Tasks:
TAKE (bread)
ALTER (bread bag) TO (minus one slice) VIA (hand) BY (lifting bread slice out of bag)
MOVE (bread slice) TO (towards plate in front of agent) VIA (hands) BY (lifting and lowering)
ALTER (plate) TO (plus one slice of bread) VIA (hand) BY (lowering bread slice onto plate)
GIVE (bread slice)
TAKE (mustard jar)
MOVE (mustard jar) TO (towards agent) VIA (hand) BY (lifting and lowering)
TAKE (mustard jar lid)
ALTER (mustard jar) TO (open) VIA (hand) BY (twisting)
MOVE (mustard jar lid) TO (towards table) VIA (hand) BY (lifting and lowering)
GIVE (mustard jar lid)

TAKE (knife)
MOVE (knife) TO (towards mustard jar) VIA (hand) BY (lifting)
ALTER (mustard jar) TO (minus one knifeful) VIA (knife) BY (scooping motion)
MOVE (knife plus mustard) TO (towards bread) VIA(hand) BY(lifting and lowering)
ALTER (bread) TO (with mustard) VIA (knife) BY (spreading motion)
MOVE (knife) TO (towards table) VIA (hand) BY (lowering)
GIVE (knife)
TAKE (mustard jar lid)
MOVE (mustard jar lid) TO (towards mustard jar) VIA (hand) BY (lifting and lowering)
ALTER (mustard jar) TO (closed) VIA (hand) BY (twisting)
GIVE (mustard jar lid)
MOVE (mustard jar) TO (side of table away from agent) VIA (hand) BY (lifting and lowering)
GIVE (mustard jar)
TAKE (cold cut package)
MOVE (cold cut package) TO (towards table in front of agent) VIA (hand) BY (lifting and lowering)
GIVE (cold cut package)
TAKE (cold cut slices (2-4))
ALTER (cold cut package) TO (minus 1-4 slices) VIA (hand) BY (lifting)
MOVE (cold cut slices) TO (bread in front of agent) VIA (hand) BY (lifting and lowering)
ALTER (bread with mustard) TO (plus cold cut slice or slices) VIA (hand) BY (lifting)
GIVE (cold cut slice)
TAKE (bread)
ALTER (bread bag) TO (minus one slice) VIA (hand) BY (lifting bread slice out of bag)

MOVE (bread slice) TO (towards bread, mustard, and cold cut slice on plate) VIA (hands) BY (lifting and lowering)
ALTER (bread, mustard, and cold cut) TO (plus one slice of bread) VIA (hand) BY (lowering bread slice)
GIVE (bread slice)
TAKE (knife)
MOVE (knife) TO (towards agent) VIA (hand) BY (lifting)
TAKE (sandwich)
MOVE (knife) TO (towards sandwich) VIA (hand) BY (lifting and lowering)
ALTER (sandwich) TO (cut in half) VIA (knife) BY (sawing or pressing down motion)
GIVE (sandwich)
MOVE (knife) TO (table away from agent) VIA (hand) BY (lifting and lowering)
GIVE (knife)

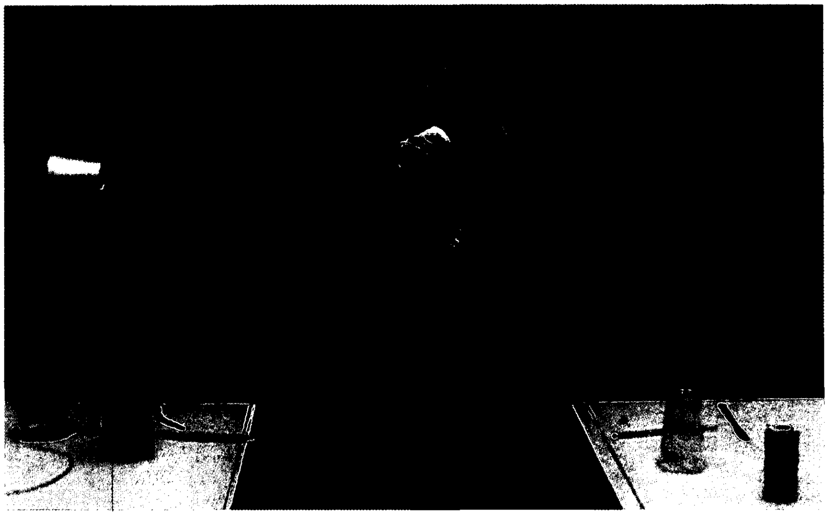
NNA: Bird Feeder



Expected Tasks:
TAKE (ball)
TAKE (stick)
MOVE (ball) TO (in front of agent) VIA (hand) BY (lifting)
MOVE (stick) TO (in front of agent) VIA (hand) BY (lifting)
ALTER (ball) TO (ball with hole) VIA (stick) BY (inserting)
MOVE (stick) TO (side of table) VIA (hand) BY (lowering)
GIVE (stick)
TAKE (pencil)
MOVE (pencil) TO (in front of agent) VIA (hand) BY (lifting)
ALTER (ball) TO (ball with larger hole) VIA (pencil) BY (inserting and twisting)
MOVE (pencil) TO (side of table) VIA (hand) BY (lowering)
GIVE (pencil)
MOVE (ball) TO (on the table) VIA (hand) BY (lowering)
GIVE (ball)
TAKE (wires)
MOVE (wires) TO (in front of agent) VIA (hand) BY (lifting)
TAKE (button)
MOVE (button) TO (in front of agent) VIA (hand) BY (lifting)
ALTER (wires) TO (wires with button) VIA (button) BY (pulling)
GIVE (button)
TAKE (ball)
MOVE (ball) TO (in front of agent) VIA (hand) BY (lifting)

ALTER (ball) TO (ball with wires and button) VIA (wires) BY (pushing and pulling wires through hole)
GIVE (ball)
ALTER (wires) TO (wires twisted) VIA (hand) BY (twisting)
MOVE (bird feeder = wires + ball + button) TO (side of table) VIA (hand) BY (lowering)
GIVE (bird feeder)
TAKE (paper)
MOVE (paper) TO (in front of agent) VIA (hand) BY (sliding)
GIVE (paper)
TAKE (glue bottle)
MOVE (glue bottle) TO (above paper) VIA (hand) BY (lifting)
TAKE (paper)
ALTER (paper) TO (prepared) VIA (glue bottle) BY (squishing)
MOVE (glue bottle) TO (side of table) VIA (hand) BY (lowering)
GIVE (glue bottle)
TAKE (bird feeder)
MOVE (bird feeder) TO (above paper) VIA (hand) BY (lifting and lowering)
ALTER (ball) TO (glued) VIA (hand and wires) BY (rolling)
ALTER (ball) TO (more glued) VIA (hand and wires) BY (rolling)
TAKE (paper)
MOVE (paper) TO (side of table) VIA (hand) BY (sliding)
GIVE (paper)
TAKE (plate with seeds)
MOVE (plate with seeds) TO (in front of agent) VIA (hand) BY (sliding)
ALTER (ball) TO (ball with seeds) VIA (hand) BY (rolling)
MOVE (birdfeeder) TO (in front of agent) VIA (hand) BY (lifting and displaying to camera)

NNA: Ear Guitar

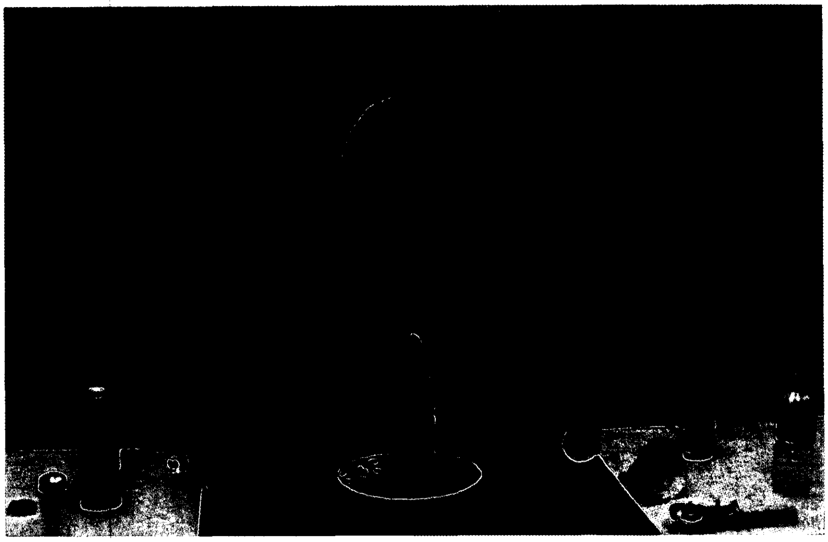


Expected Tasks:
TAKE (cups)
MOVE (cups) TO (in front of agent) VIA (hands) BY (sliding)
TAKE (top cup)
MOVE (top cup) TO (away from bottom cup) VIA (hand) BY (lifting & placing)
GIVE (left cup from actor's perspective)
TAKE (pin)
MOVE (pin) TO (left cup) VIA (hand) BY (lifting)
ALTER (left cup) TO (hole in centre) VIA (pin) BY (inserting pin into bottom portion)
GIVE (left cup)
TAKE (right cup from actor's perspective)
MOVE (pin) TO (right cup) VIA (hands) BY (lifting)
ALTER (right cup) TO (hole in centre) VIA (pin) BY (inserting pin into bottom portion of cup)
GIVE (right cup)
MOVE (pin) TO (side of table) VIA (hand) BY (lowering)
GIVE (pin)
TAKE (pencil)
MOVE (pencil) TO (above left cup) VIA (hand) BY (lifting)
TAKE (left cup)
ALTER (left cup) TO (larger hole) VIA (pencil) BY (inserting & twisting)
GIVE (left cup)
MOVE (pencil) TO (right cup) VIA (hand) BY (lifting)
TAKE (right cup)
ALTER (right cup) TO (larger hole) VIA (pencil) BY (inserting & twisting)
GIVE (right cup)
MOVE (pencil) TO (side of table) VIA (hand) BY (lowering)

GIVE (pencil)
TAKE (left cup & right cup)
MOVE (left cup & right cup) TO (away from agent) VIA (hands) BY (lifting & lowering)
GIVE (left cup & right cup)
TAKE (ruler)
MOVE (ruler) TO (in front of agent, on table) VIA (hand) BY (lifting or sliding)
GIVE (ruler)
TAKE (spool of string)
MOVE (spool of string) TO (in front of agent) VIA (hand) BY (lifting)
TAKE (end of string)
ALTER (spool of string) TO (unraveled) VIA (hands) BY (unrolling approximately a ruler's length)
MOVE (string) TO (table by ruler) VIA (hands) BY (placing)
ALTER (string) TO (measured) VIA (ruler) BY (aligning string along ruler)
ALTER (string) TO (measured) VIA (ruler) BY (overlapping string along ruler towards starting point of measurement)
GIVE (string)
TAKE (scissors)
MOVE (scissors) TO (end by spool) VIA (hand) BY (lifting)
ALTER (spool of string) TO (full minus unrolled string) VIA (scissors) BY (cutting)
MOVE (scissors) TO (away from agent) VIA (hand) BY (lowering)
MOVE (spool of string) TO (away from agent) VIA (hand) BY (lowering)
GIVE (scissors)
GIVE (spool of string)
TAKE (ruler)
MOVE (ruler) TO (away from agent) VIA (hand) BY (sliding)
GIVE (ruler)
TAKE (vaseline)
MOVE (vaseline) TO (closer to agent) VIA (hand) BY (lifting and lowering or sliding)
ALTER (vaseline) to (uncovered) VIA (hand) BY (removing cap)
TAKE (cut string)
MOVE (cut string) TO (upper position, towards agent) VIA (hand) BY(lifting)
MOVE (Vaseline) TO (one end of string) VIA (fingertip) BY (lifting)
ALTER (end of string) TO (lubricated) VIA (vaseline) BY (rubbing with fingertips)
TAKE (more vaseline)
MOVE (vaseline) TO (other end of string) VIA (fingertip) BY (lifting)
ALTER (other end of string) TO (lubricated) VIA (vaseline) BY (rubbing with fingertips)
TAKE (vaseline)
MOVE (vaseline) TO (away from agent) VIA (hand) by (lifting or sliding)
GIVE (vaseline)
TAKE (left cup & right cup one at a time or together)

MOVE (left cup & right cup) TO (in front of agent) VIA (hand) BY (lifting)
GIVE (left cup & right cup)
MOVE (one end of string) TO (right cup) VIA (hands) BY (lowering)
ALTER (right cup) TO (string in centre) VIA (string) BY (inserting end of string into hole in right cup)
MOVE (other end of string) TO (left cup) VIA (hands) BY (lowering)
TAKE (left cup)
ALTER (left cup) TO (string in centre) VIA (string) BY (inserting end of string into hole in left cup)
MOVE (left cup) TO (upper position, rotated) VIA (hand) BY (lifting & rotating)
TAKE (end of string in left cup)
MOVE (string) TO (through hole in left cup) VIA (hand) BY (pulling)
MOVE (left cup) TO (on the table) VIA (hand) BY (lowering)
GIVE (left cup)
ALTER (end of string) TO (folded) VIA (hand) BY (folding over & pinching together one inch of string)
TAKE (a plastic clip)
MOVE (plastic clip) TO (end of string) VIA (hand) BY (lifting)
ALTER (folded end of string) TO (clipped) VIA (plastic clip) BY (inserting plastic clip onto end of string)
GIVE (Plastic clip + end of string)
TAKE (right cup)
MOVE (right cup) TO (upper position, rotated) VIA (hand) BY (lifting & rotating)
TAKE (string in right cup)
MOVE (string) TO (through hole in cup) VIA (hand) BY (pulling)
MOVE (right cup) TO (on the table) VIA (hand) BY (lowering)
GIVE (right cup)
ALTER (end of string) TO (folded) VIA (hand) BY (folding over & pinching together one inch of string)
TAKE (plastic clip)
MOVE (plastic clip) TO (end of string) VIA (hand) BY (lifting)
ALTER (folded end of string) TO (clipped) VIA (plastic clip) BY (inserting plastic clip into end of string)
GIVE (plastic clip + end of string)
TAKE (left cup & right cup)
MOVE (right cup) TO (upper position, toward agent) VIA (hand) BY (lifting)
MOVE (left cup & right cup) TO (away from each other) VIA (hand) BY (lifting & pulling apart)

NNA: Mock Volcano

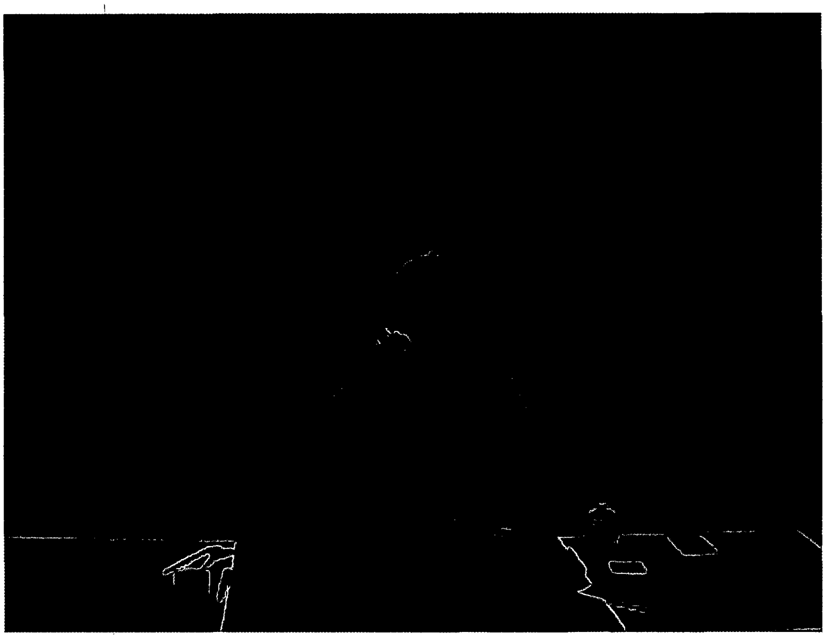


Expected Tasks:
TAKE (plate)
MOVE (plate) TO(in front of agent) VIA(hands) BY(lifting)
GIVE (plate)
TAKE (bottle)
MOVE (bottle) TO(middle of plate) VIA(hands) BY(lifting)
GIVE (bottle)
TAKE (large funnel)
MOVE (large funnel) TO(above bottle) VIA(hands) BY(lifting and inserting into bottle)
GIVE(large funnel)
TAKE(yeast can)
MOVE(yeast can) TO(in front of agent) VIA(hands) BY(lifting)
TAKE(yeast can lid)
ALTER(yeast can) TO(opened) VIA(hands) BY(unscrewing lid)
Move(lid) To(on the table) VIA(hand) BY(lowering)
GIVE (lid)
GIVE (yeast can)
TAKE(spoon)
MOVE(spoon) TO (yeast can) VIA(hand) BY(lifting and lowering into can)
TAKE (yeast can)
ALTER (yeast) TO(full minus one scoop) VIA(spoon) BY(scooping one scoop full of yeast)
GIVE (yeast can)
TAKE (funnel)
ALTER(bottle) TO(empty plus one spoon of yeast) VIA(spoon) BY(emptying contents of spoon into bottle via funnel)
MOVE(spoon) TO (away from over funnel) VIA(hand) BY(lifting and lowering}
MOVE(large funnel) TO(away from bottle) VIA(hand) BY(lifting and lowering)

GIVE (large funnel)
GIVE (spoon)
TAKE (yeast lid)
TAKE (yeast can)
ALTER (yeast can) TO (closed)
MOVE (yeast can) TO (side of table)
GIVE(yeast can)
TAKE (cone top)
TAKE (bottle)
MOVE (cone top) TO(over bottle) VIA(hand) BY(lifting and lowering)
GIVE(cone)
GIVE (bottle)
TAKE (plate)
MOVE (plate) TO(away from agent ~ 2 inch.) VIA(hands) BY(pushing)
GIVE (plate)
TAKE(measuring cup)
MOVE (measuring cup) TO (in front of agent) VIA (hand) BY (lifting)
GIVE (measuring cup)
TAKE (peroxide bottle)
MOVE (peroxide bottle) TO(in front of agent) VIA(hands) BY(lifting)
TAKE (peroxide lid)
ALTER(peroxide bottle) TO(opened) VIA(lid) BY (twisting top off)
MOVE(lid) TO(away from agent) VIA(hands) BY(lifting and lowering)
GIVE(lid)
MOVE(opened peroxide bottle) TO(above measuring cup) VIA(hand) BY(lifting and tilting on side)
ALTER(measuring cup) TO(filled with some peroxide) VIA(hand) BY(pouring peroxide into measuring cup)
TAKE (peroxide bottle lid)
MOVE(lid) TO(above peroxide bottle) VIA(hand) BY(lifting and lowering)
ALTER(peroxide bottle) TO(closed) VIA(hands) BY(twisting top onto peroxide bottle)
GIVE(lid)
MOVE(bottle) TO(away from agent) VIA(hand) BY(lifting)
GIVE(peroxide bottle)
TAKE (measuring cup)
MOVE (measuring cup) TO (away from of agent) VIA (hands) BY (sliding)
GIVE (measuring cup)
TAKE (plate)
MOVE (plate) TO (in front of agent) VIA (Hand) BY (sliding)
GIVE (plate)
TAKE (small funnel)
MOVE(small funnel) TO (inserted in cone top over bottle) VIA(hand) BY (lifting, inverting and lowering so that spout faces down)
TAKE (measuring cup)
MOVE(measuring cup with peroxide) TO(above small funnel) VIA(hand) BY(lifting and tilting

on side)
ALTER(bottle) TO(filled with peroxide) VIA(measuring cup) BY(lifting and pouring peroxide into funnel)
MOVE(measuring cup) TO(away from over small funnel) VIA(hand) BY(lifting and lowering)
MOVE(small funnel) TO (away from bottle) VIA(hand) BY(lifting and lowering)
GIVE (small funnel)
GIVE (measuring cup)

NNA: Door Hanger



Expected Tasks:
TAKE (2 Popsicle sticks one at a time or together)
MOVE (2 Popsicle sticks one at a time or together) TO(paper in front of agent) VIA (hands) BY (lifting and lowering placing them horizontally ~ 1 cm apart)
GIVE (2 Popsicle sticks)
TAKE(glue bottle)
MOVE (glue bottle) TO(above popsicle stick #1 on the right side (actor's perspective) furthest away from agent) VIA(hands) BY(lifting and inverting so that nozzle faces down towards popsicle sticks).
TAKE (popsicle sticks #1 and #2}.
ALTER(Popsicle stick #1 and #2) TO(with glue) VIA(glue bottle) BY (squeezing glue on the right ends of (actor's perspective) Popsicle sticks #1 and #2)
MOVE (glue bottle) TO(above popsicle stick #1 on the left side (actor's perspective) furthest away from agent) VIA(hands) BY(lifting and inverting so that nozzle faces down towards popsicle sticks).

ALTER(Popsicle stick #1 and #2) TO(with glue) VIA(glue bottle) BY (squeezing glue on the left ends of (actor's perspective) Popsicle sticks #1 and #2)
GIVE (popsicle stick #1 and #2).
MOVE (glue bottle) TO(away from popsicle sticks) VIA(hands) BY(lifting and lowering)
GIVE (glue bottle)
TAKE (2 horizontal popsicle sticks).
MOVE (2 horizontal Popsicle sticks) TO (~ 2 cm more apart) VIA (hands) BY(sliding)
GIVE (2 horizontal popsicle sticks)
TAKE (6 Popsicle sticks)
MOVE (6 Popsicle sticks) TO(left of agent)VIA(hands) BY(lifting)
GIVE (Popsicle sticks)
TAKE { Popsicle stick #1}
MOVE (one popsicle stick) TO (above horizontal popsicle sticks on paper in front of agent) VIA (hand) BY (lifting and lowering)
ALTER (horizontal sticks) TO (with one vertical stick) VIA (hand) BY (affixing one vertical stick on the outer left edge of the horizontal sticks).
GIVE (stick).
TAKE (a 2nd popsicle stick).
MOVE (2nd popsicle stick) TO (above horizontal popsicle sticks) VIA (hand) BY (lifting)
ALTER (horizontal sticks) TO (with two vertical sticks) VIA (hand) BY (affixing the 2nd vertical stick beside the first vertical stick on the outer left edge of the horizontal sticks).
GIVE (popsicle stick).
TAKE (a 3rd popsicle stick).
MOVE (3rd popsicle stick) TO (above horizontal popsicle sticks) VIA (hand) BY (lifting)
ALTER (horizontal sticks) TO (with three vertical sticks) VIA (hand) BY (affixing the 3rd vertical stick beside the first and second vertical popsicle sticks on the outer left edge of the horizontal sticks).
GIVE (popsicle stick).
TAKE (a 4th popsicle stick).
MOVE (4th popsicle stick) TO (above horizontal popsicle sticks) VIA (hand) BY (lifting)
ALTER (horizontal sticks) TO (with four vertical sticks) VIA(hands) BY (affixing the 4th stick vertically on the inner right edge of the horizontal popsicle sticks).
GIVE (popsicle stick).
TAKE (a 5th popsicle stick).
MOVE (5th popsicle stick) TO (above horizontal popsicle sticks) VIA (hand) BY (lifting)
ALTER (horizontal sticks) TO (with five vertical sticks) VIA(hands) BY (affixing the 5th stick vertically beside the fourth stick on the outer right edge of the horizontal popsicle sticks).
GIVE (popsicle stick).
TAKE (a 6th popsicle stick).
MOVE (6th popsicle stick) TO (above horizontal popsicle sticks) VIA (hand) BY (lifting)
ALTER (horizontal sticks) TO (with six vertical sticks) BY (affixing the sixth stick vertically, beside the fifth stick, on the outer right edge of the horizontal popsicle sticks).

GIVE (popsicle stick).
MOVE (6 vertical popsicle sticks) TO (2 horizontal popsicle sticks) VIA (hands) BY (pressing in a downward manner)
TAKE (partially completed door hanger)
MOVE (partially completed door hanger) TO(away from agent) VIA(hands) BY(sliding)
GIVE(partially completed door hanger)
TAKE(pink paper)
MOVE(pink paper) TO(in front of agent) VIA(hands) BY(sliding)
GIVE (pink paper)
TAKE (square stencil)
MOVE(square stencil) TO(pink paper in front of agent) VIA(hands) BY(lifting and lowering)
TAKE(pencil)
MOVE (pencil) TO (above square stencil) VIA (hand) BY (lifting and lowering).
ALTER(paper) TO(drawn on) VIA(pencil) BY(tracing around the outer edges of the square stencil)
MOVE (pencil) TO (away from paper) VIA (hand) BY (lifting and lowering).
GIVE (pencil).
MOVE (square stencil) TO (away from pink paper) VIA (hand) BY (lifting).
GIVE (square stencil).
TAKE(scissors)
TAKE(pink paper)
MOVE(scissors) TO(towards pink paper) VIA(hands) BY (lifting)
MOVE(pink paper) TO(off of table) VIA(hands) BY(lifting)
ALTER(paper) TO(cut around tracing) VIA(scissors) BY(snipping or cutting)
MOVE (scissors) TO (away from paper) VIA (hand) BY (lifting)
GIVE (scissors)
TAKE (excess pink paper).
MOVE (excess pink paper) TO (away from agent) VIA (hand) BY (lifting).
GIVE (excess pink paper)
TAKE(marker)
MOVE(marker) TO(in front of agent) VIA(hands) BY(lifting)
TAKE (marker cap).
ALTER(marker) TO(opened) VIA(hands) BY(pulling top off)
MOVE(marker cap) TO(away from agent) VIA(hands) BY(lifting and lowering)
GIVE (marker cap)
TAKE(square traced paper)
MOVE(square traced paper) TO(in front of agent) VIA(hands) BY(sliding)
MOVE(marker) TO(over square traced paper) VIA(hands) BY(lifting)
ALTER(square traced paper) TO(drawn) VIA(marker) BY(marking on it)
MOVE (marker) TO (toward agent) VIA (hand) BY (lifting).
TAKE (marker cap)
MOVE(lid) TO(marker) VIA(hand) BY(lifting)
ALTER (marker) TO(closed) VIA(hands) BY(pushing lid in)

GIVE (marker cap)
MOVE (closed marker) TO (away from agent) VIA(hand) BY (lifting and lowering)
GIVE (marker)
GIVE (square traced paper)
TAKE (square traced paper)
MOVE (square traced paper) TO (inverted) VIA (hand) BY (turning so that marked side faces down).
GIVE (square traced paper).
TAKE (glue bottle)
TAKE (square traced paper)
MOVE(glue bottle) TO(inverted over square traced paper) VIA(hands) BY(lifting and lowering)
ALTER (drawn on square traced paper) TO(with glue) VIA(glue) BY(squeezing glue onto each corner of the square traced paper)
GIVE(square traced paper)
MOVE (glue bottle) TO(away from square traced paper) VIA(hand) BY (lifting)
GIVE (glue)
TAKE (partially completed door hanger)
MOVE(partially completed door hanger) TO (in front of agent) VIA(hands) BY(sliding)
GIVE (partially completed door hanger)
TAKE (square traced paper)
MOVE (square traced paper) TO (above popsicle sticks) VIA(hands) BY(lifting and inverting so that marked side faces up)
ALTER (popsicle sticks) TO(with square traced paper) VIA(hands) BY(lowering and pressing square traced paper down on popsicle sticks)
GIVE (square traced paper)
TAKE (partially completed door hanger)
MOVE(partially completed door hanger) TO (inverted) VIA(hands) BY(turning over)
GIVE (partially completed door hanger)
TAKE(piece of string)
MOVE(string) TO (above sticks) VIA(hands) BY(lifting and placing one end of string to the top left and one end to the top right corners of vertical popsicle sticks)
GIVE(string)
TAKE (scotch tape dispenser)
TAKE (end of tape).
ALTER (end of tape) TO (ripped) VIA(hands) BY (pulling out and down)
GIVE (roll of tape)
GIVE (scotch tape dispenser)
MOVE(ripped piece of tape) TO(above end of string at left side of vertical sticks) VIA(hands) BY(lifting and lowering)
ALTER (popsicle sticks) TO (with string) VIA (tape) BY (pressing tape to string on front top left side (actor's perspective) of vertical popsicle stick).
GIVE(tape)
TAKE (scotch tape dispenser)
TAKE (end of tape)
ALTER(tape) TO(ripped) VIA(hand) BY(pulling out and down)

GIVE(scotch tape dispencer)
MOVE(tape) TO(over top right side of vertical popsicle sticks) VIA(hand) BY(lifting)
ALTER (popsicle sticks) TO (with string) VIA (tape) BY (pressing tape to string on front top right side of vertical popsicle stick).
GIVE(tape)
TAKE (door hanger by string)
MOVE (complete door hanger) TO(face camera) VIA(hands) BY(grasping attached string by the centre and holding it up)

Replacement NNA: Compass (no photo available)

Expected Tasks:
TAKE sponge
MOVE sponge TO in front of agent VIA hand BY lifting
GIVE sponge
TAKE marker
MOVE marker TO in front of agent VIA hand BY lifting
TAKE marker lid
ALTER marker TO open VIA lid BY taking the lid off
MOVE marker TO above sponge VIA hand BY lowering
TAKE sponge
ALTER sponge TO coloured VIA marker BY drawing an "N"
GIVE sponge
ALTER marker TO closed VIA lid BY putting lid back on
MOVE marker TO side of table VIA hand BY lowering
GIVE marker
TAKE sponge
MOVE sponge TO right of agent VIA hand BY lifting & lowering
GIVE sponge
TAKE pyrex dish
MOVE pyrex dish TO in front of agent VIA hands BY lifting & lowering
GIVE pyrex dish
TAKE pitcher
MOVE pitcher TO above pyrex dish VIA hand BY lifting
ALTER pyrex dish TO filled with some water VIA pitcher BY pouring water into pyrex dish
MOVE pitcher TO on table VIA hand BY lowering
GIVE pitcher
TAKE sponge
MOVE sponge TO middle of water-filled pyrex dish VIA hand BY lifting & lowering
GIVE sponge
TAKE pyrex dish
MOVE pyrex dish TO away from agent VIA hand BY sliding

GIVE pyrex dish
TAKE magnet
MOVE magnet TO in front of agent VIA hand BY lifting & lowering
GIVE magnet
TAKE needle
MOVE needle TO in front of agent VIA hand BY lifting & lowering
TAKE magnet
ALTER needle TO magnetized VIA hand BY rubbing needle against magnet
MOVE magnet TO away from agent VIA hand BY lowering
GIVE magnet
MOVE needle TO on sponge VIA hand BY lowering
GIVE needle
TAKE pyrex dish
MOVE pyrex dish TO in front of agent VIA hand BY sliding
GIVE pyrex dish
TAKE compass
MOVE (compass) TO (in front of agent) VIA (hand) by (lifting)
ALTER compass TO open VIA hands BY unclipping from top to bottom
MOVE compass TO edge of pyrex dish VIA hand BY lowering
ALTER compass TO working/so it points North VIA hands BY holding compass steady
MOVE compass TO in front of agent VIA hand BY lifting
ALTER compass TO close VIA hands BY clipping top to bottom
MOVE compass TO on table VIA hand BY lowering
GIVE compass

Appendix D

Breakdown of Novel and Routine Naturalistic Action Stimuli

Naturalistic Action	Crux Actions (N)	Noncrux Actions (N)	Photos (N)
Novel			
Birdfeeder	9	38	8
Door Hanger	30	102	7
Ear Guitar	22	73	8
Volcano	13	60	8
Mean (SD)	18.5 (9.40)	68.25 (26.74)	7.75 (0.50)
Routine			
Making Coffee	20	50	6
Mailing Card	16	57	7
Making a Sandwich	11	34	6
Mean (SD)	15.6 (4.51)	45.0 (9.54)	6.3 (0.58)

Appendix E

Experiment 1: Counterbalance Sheet

Participant Name	No.	Order									
	1	Photo; then Enact	**Practice Novel** Pinhole Camera	**Novel** Birdfeeder	**Novel** Volcano	**Novel** Ear Guitar	**Novel** Door Hanger	**Practice Routine** Draw Circle	**Routine** Coffee	**Routine** Card	**Routine** Sandwich
	2	Photo; then Enact	**Practice Routine** Draw Circle	**Routine** Coffee	**Routine** Sandwich	**Routine** Card	**Practice Novel** Pinhole Camera	**Novel** Ear Guitar	**Novel** Door Hanger	**Novel** Birdfeeder	**Novel** Volcano
	3	Photo; then Enact	**Practice Novel** Pinhole Camera	**Novel** Ear Guitar	**Novel** Door Hanger	**Novel** Birdfeeder	**Novel** Volcano	**Practice Routine** Draw Circle	**Routine** Card	**Routine** Sandwich	**Routine** Coffee
	4	Photo; then Enact	**Practice Routine** Draw Circle	**Routine** Card	**Routine** Coffee	**Routine** Sandwich	**Practice Novel** Pinhole Camera	**Novel** Birdfeeder	**Novel** Volcano	**Novel** Ear Guitar	**Novel** Door Hanger
	5	Photo; then Enact	**Practice Novel** Pinhole Camera	**Novel** Door Hanger	**Novel** Birdfeeder	**Novel** Volcano	**Novel** Ear Guitar	**Practice Routine** Draw Circle	**Routine** Sandwich	**Routine** Card	**Routine** Coffee
	6	Photo; then Enact	**Practice Routine** Draw Circle	**Routine** Sandwich	**Routine** Coffee	**Routine** Card	**Practice Novel** Pinhole Camera	**Novel** Volcano	**Novel** Ear Guitar	**Novel** Door Hanger	**Novel** Birdfeeder
	7	Enact; then Photo	**Practice Novel** Pinhole	**Novel** Volcano	**Novel** Ear Guitar	**Novel** Door	**Novel** Birdfeeder	**Practice Routine** Draw Circle	**Routine**	**Routine** Card	**Routine** Sandwich

			Camera			Hanger			Coffee		
	8	Enact; then Photo	**Practice** **Routine** Draw Circle	**Routine** Coffee	**Routine** Sandwich	**Routine** Card	**Practice** **Novel** Pinhole Camera	**Novel** Door Hanger	**Novel** Birdfee der	**Novel** Volcano	**Novel** Ear Guitar
	9	Enact; then Photo	**Practice** **Novel** Pinhole Camera	**Novel** Door Hanger	**Novel** Ear Guitar	**Novel** Volcano	**Novel** Birdfeeder	**Practice** **Routine** Draw Circle	**Routine** Card	**Routine** Sandwich	**Routine** Coffee
	10	Enact; then Photo	**Practice** **Routine** Draw Circle	**Routine** Card	**Routine** Coffee	**Routine** Sandwich	**Practice** **Novel** Pinhole Camera	**Novel** Volcano	**Novel** Birdfee der	**Novel** Door Hanger	**Novel** Ear Guitar
	11	Enact; then Photo	**Practice** **Novel** Pinhole Camera	**Novel** Volcano	**Novel** Birdfeede r	**Novel** Door Hanger	**Novel** Ear Guitar	**Practice** **Routine** Draw Circle	**Routine** Sandwic h	**Routine** Card	**Routine** Coffee
	12	Enact; then Photo	**Practice** **Routine** Draw Circle	**Routine** Sandwich	**Routine** Coffee	**Routine** Card	**Practice** **Novel** Pinhole Camera	**Novel** Door Hanger	**Novel** Ear Guitar	**Novel** Volcano	**Novel** Birdfeede r

Appendix F

Psychological Tests Administered

Test	*Norms*
Mental Status	
Modified Mini Mental State Examination	Bravo & Hebert, 1997
Language	
Western Aphasia Battery - Spontaneous Speech and Comprehension subtests	Kertesz, 1982
Executive Function	
Trail Making Test (Part A & B)	Spreen & Strauss, 1998
Stroop Test – Victoria Version	Troyer, Leach, & Strauss, 2006
Letter Fluency Test (F, A, and S)	Spreen & Benton, 1977
Wechsler Memory Scale-Revised – Backward Digit Span subtest	Wechsler, 1987
Declarative Memory	
Brief Visuospatial Memory Test – Revised (BVMT-R)	Benedict, 1997
Hopkins Verbal Learning Test – Revised (HVLT-R)	Benedict, Schretlen, Groninger, & Brandt, 1998

Appendix G

Experiment 1: Descriptive Neuropsychological Test Performance for Participants with Stroke

Measure	Participants with Stroke (n = 16)	
	M	SD
Episodic Memory		
HVLT-R: Total Recall z-score	-1.63	1.11
HVLT-R: Delay z-score	-1.55	0.91
BVMT-R: Total Recall z-score	-0.50	1.33
BVMT-R: Delay z-score	-0.56	1.17
Associative Memory		
BVMT-R: Corrected Associative Memory Score*	0.82	0.34
Executive Function		
Victoria Stroop Ratio of Interference z-score	0.86	1.26
Clock Drawing Total Time z-score	0.00	1.00
TMT B Completion Time z-score	-1.91	1.82
Phonemic Fluency (FAS Total) z-score	-1.16	0.99

Note. HVLT-R = Hopkins Verbal Learning Test- Revised; BVMT-R = Brief Visuospatial Memory Test- Revised; TMT B = Trail Making Test B.

*. Corrected associative scores ranged from 0 to 1. It was not possible to calculate z-scores due to no normative data.

Appendix H

Table H.1. Summary of NNA T3 Regression Analysis for Variables Predicting Crux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.204	.038	
Associative Memory	-.177	.043	-.791**
Model 2			
Constant	.212	.069	
Associative Memory	-.189	.061	-.843*
Episodic Memory Composite	.029	.028	.382
Executive Function Composite	-.042	.024	-.498

R^2 = .625 for Model 1 (p = .002); R^2 change = .102 for Model 2 (p = .280)
* $p < .05$; ** $p < .01$

Table H.2. Summary of NNA T3 Regression Analysis for Variables Predicting Noncrux Omissions

Variables	*B*	SE B	β
Model 1			
constant	.326	.055	
Associative Memory	-.215	.062	-.738**
Model 2			
constant	.281	.110	
Associative Memory	-.185	.097	-.634
Episodic Memory Composite	.000	.045	-.007
Executive Function Composite	-.024	.039	-.223

$R^2 = .545$ for Model 1 ($p = .006$); R^2 change $= .042$ for Model 2 ($p = .682$)
* $p < .05$; ** $p < .01$

Table H.3. Summary of NNA T3 Regression Analysis for Variables Predicting Crux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.309	.066	
Associative Memory	-.258	.075	-.735**
Model 2			
Constant	.321	.132	
Associative Memory	-.273	.118	-.778
Episodic Memory Composite	.031	.055	.261
Executive Function Composite	-.043	.047	-.326

R^2 = .541 for Model 1 (p = .006); R^2 change = .043 for Model 2 (p = .673)
* $p < .05$; ** $p < .01$

Table H.4. Summary of NNA T3 Regression Analysis for Variables Predicting Noncrux Commissions

Variables	*B*	SE B	β
Model 1			
constant	.080	.019	
Associative Memory	-.045	.021	-.555
Model 2			
constant	.079	.039	
Associative Memory	-.044	.035	-.547
Episodic Memory Composite	-.003	.016	-.095
Executive Function Composite	.004	.014	.135

R^2 = .308 for Model 1 (p = .061); R^2 change = .008 for Model 2 (p = .956)

Appendix I

Experiment 2: Counterbalance Sheet

Participant Name	#	Order						
	1	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (V)	FD (B)	DF (E)
	2	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (B)	DF (E)	FF (V)
	3	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (E)	FF (V)	FD (B)
	4	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (B)	FD (E)	DF (V)
	5	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (E)	DF (V)	FF (B)
	6	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (V)	FF (B)	FD (E)
	7	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (E)	FD (V)	DF (B)
	8	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (V)	DF (B)	FF (E)
	9	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (B)	FF (E)	FD (V)
	10	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (V)	FD (B)	DF (E)
	11	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (B)	DF (E)	FF (V)

	12	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (E)	FF (V)	FD (B)
	13	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (B)	FD (E)	DF (V)
	14	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (E)	DF (V)	FF (B)
	15	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (V)	FF (B)	FD (E)
	16	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FF (E)	FD (V)	DF (B)
	17	Photo, Enact	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	FD (V)	DF (B)	FF (E)
	18	Enact, Photo	Practice (2nd task)	Practice (Pinhole)	FA (2nd task)	DF (B)	FF (E)	FD (V)

Appendix J

Experiment 2: Descriptive Neuropsychological Test Performance for Participants with Stroke

Measure	Low Error Producers (n = 9)		High Error Producers (n = 9)		Full Stroke Group (n = 18)	
	M	SD	M	SD	M	SD
Episodic Memory						
HVLT-R: Total Recall z-score	-0.91	0.68	-1.90	1.00	-1.38	0.96
HVLT-R: Delay z-score	-0.78	0.82	-1.69	0.59	-1.21	0.84
BVMT-R: Total Recall z-score	0.44	0.86	-1.70	0.94	-0.70	1.41
BVMT-R: Delay z-score	0.40	0.41	-1.83	1.04	-0.79	1.39
Associative Memory						
BVMT-R: Corrected Associative Memory Score*	2.22	1.24	0.56	1.01	1.34	1.38
Executive Function						
TMT B Completion Time z-score	-0.21	0.66	-2.04	3.16	-1.13	2.40
Victoria Stroop Color Time z-score	-0.56	1.26	-0.76	1.00	0.46	1.49
Victoria Stroop Color Errors z-score	-0.28	2.32	-0.47	1.91	-0.37	2.08
Victoria Stroop Ratio of Interference z-score	-0.18	1.55	-1.19	1.08	-0.65	1.11

Note. HVLT-R = Hopkins Verbal Learning Test- Revised; BVMT-R = Brief Visuospatial Memory Test- Revised; TMT B = Trail Making Test B.

*. Corrected associative scores ranged from 0 to 1. It was not possible to calculate z-scores due to no normative data.

Appendix K

Figure K.1. Top row shows overlap of 11 participant lesions. Bottom row demonstrates results of voxel-wise analysis indicating areas with lesions that were significantly related to NNA T2 commission noncrux error rate. *Note*. Om = Omission Error; Comm. = Commission Error.

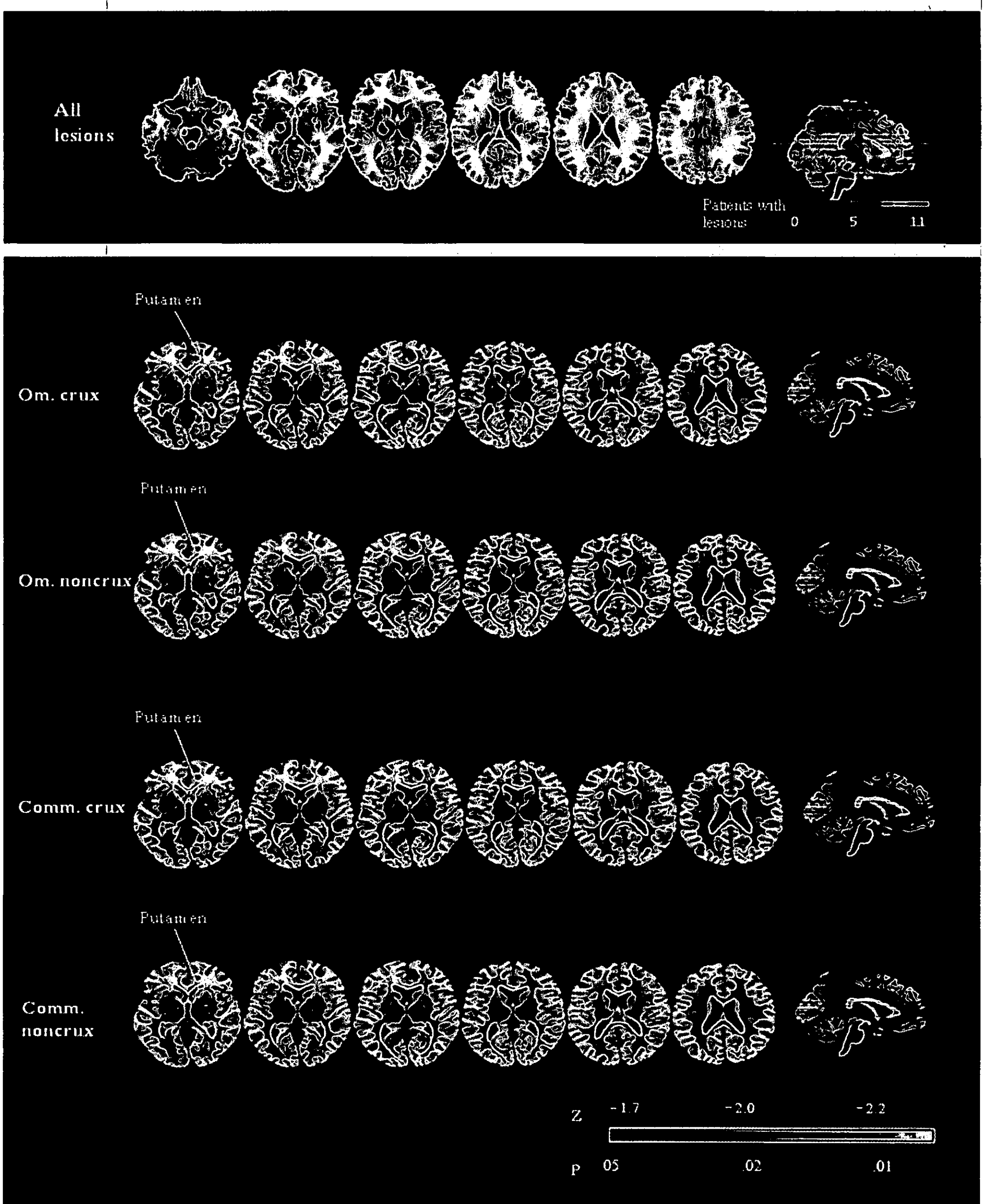


Figure K.2. Top row shows overlap of 11 participant lesions. Bottom row demonstrates results of voxel-wise analysis indicating areas with lesions that were significantly related to NNA T3 commission noncrux error rate. *Note.* Om. = Omission Error; Comm. = Commission Error.