LONG-TERM RETENTION OF SKILLED VISUAL SEARCH

FOLLOWING SEVERE CLOSED-HEAD INJURY

By

SHITAL PRABODH PAVAWALLA

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The members of the Committee appointed to examine the thesis of SHITAL PRABODH PAVAWALLA find it satisfactory and recommend that it be accepted.

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Chair

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Abstract

by Shital Prabodh Pavawalla, M.S.
Washington State University
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Chair: Maureen Schmitter-Edgecombe

Seventeen closed-head injured (CHI) and 10 control participants who had earlier received extensive consistent-mapping (CM) training (i.e., 3600 trials) in a semantic category visual search task (Schmitter-Edgecombe & Beglinger, 2001), received follow-up testing following a long-term (5 or 10 month) retention interval. In a CM training situation, individuals always respond in the same way to a specific class of stimuli (e.g., the category exemplar "arm" always requires the same response). Following initial CM training, both the CHI and control groups demonstrated dramatic performance improvements and the development of an automatic attention response (AAR), indicating both task-specific and stimulus-specific learning. In this study, retention for task-specific and stimulus-specific aspects of skilled visual search was assessed using new CM stimuli and the originally trained CM stimuli, respectively. No significant group differences were found in the level of retention for either skill type, indicating that individuals with a CHI were able to retain task-specific and stimulus-specific skills over a long-term retention interval without practice at a level comparable to normal controls. Exploratory analyses also revealed that the CHI participants that returned for the 5-month retention interval showed greater skill retention that those that returned at the 10-month interval.

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Dedication

This thesis is dedicated to my family who provided me with the motivation, strength, and encouragement to persevere via their support, thoughts, prayers, and love.

CHAPTER ONE

INTRODUCTION

Individuals with closed-head injuries (CHIs) constitute a large proportion of those who require extensive post-hospitalization rehabilitation. Central to successful remediation is the ability to develop and retain new complex cognitive skills, post-injury. Because automatic component processes serve as fundamental building blocks for complex cognitive skills (Fisk & Rogers, 1992; Logan, 1985), a better understanding of the development and retention of automatic processes after CHIs could have important implications for remediation. In previous work with severe CHI patients who were more than one year post-injury, our lab demonstrated that individuals with a CHI were able to successfully learn to automatize new complex cognitive skills (Schmitter-Edgecombe & Beglinger, 2001; Schmitter-Edgecombe & Rogers, 1997). In the present study, we extend this research by examining long-term retention of automatic processes that were acquired following extended practice with a semantic category visual search task (Schmitter-Edgecombe & Beglinger, 2001).

Automatic processing can be described as rapid processing that requires minimal conscious control or effort. In contrast, controlled processing tends to be slow, serial, and under the conscious control of the individual (Schneider & Shiffrin, 1977). An example of these processes can be understood in terms of driving a car. Initially, maneuvering a large vehicle with its many devices, while keeping your eyes on the road and the car's mirrors, is a difficult task that requires a great deal of conscious attention and concentration. However, with practice, such actions become more and more familiar and less attention demanding. The former stage can be viewed as controlled processing while the latter can be understood as automatic processing. The key differentiation between controlled and automatic processing is that of attention – controlled processing relies heavily upon an individual consciously attending to the given task while automatic processing occurs with little or no conscious attention. For this reason, multiple controlled processes generally cannot be performed efficiently under situations with a high workload, whereas automatic processes can be performed simultaneously with ongoing tasks that involve a larger workload (Schneider & Chein, 2003).

Because automatic processes are important in complex skill development and may play an important role in cognitive remediation, several studies have examined automatic processes within the CHI population (e.g., Schmitter-Edgecombe, Marks, & Fahy, 1993; Schmitter-Edgecombe & Rogers, 1997; Schmitter-Edgecombe & Nissley, 2000; Vakil, Blachstein, & Hoofien, 1991). Most of these studies, however, have examined the preservation of those automatic processes that were developed prior to injury. In general, this research supports the notion that those processes that were automatized prior to injury are intact in CHI participants who are more than one-year post-injury (e.g., Schmitter-Edgecombe, Marks, & Fahy, 1993; Schmitter-Edgecombe & Nissley, 2000; Vakil, Blachstein, & Hoofien, 1991). In addition to processes automatized prior to injury, a second important question involves the ability to develop new automatic processes following severe closed-head injuries. Very few studies have examined the development of new complex skills post-injury in a CHI population.

In two recent studies, using semantic-category memory and visual search tasks, Schmitter-Edgecombe and colleagues (Schmitter-Edgecombe & Rogers, 1997; Schmitter-Edgecombe & Beglinger, 2001) demonstrated that severe CHI participants can successfully learn to automatize cognitive components of complex tasks. In both studies, by manipulating the consistency of practice, they were able to develop a situation where automatic processing could develop (consistent mapping training), and one where controlled processing was continually required (varied mapping training). Consistent mapping (CM) involves repetitive training in a given non-varying condition. During a consistent mapping situation, participants always respond the same way to a specific class of stimuli across a large number of trials (e.g., > 1,800). For example, in a category search, whenever the category exemplar "arm" appears in the visual display, it would always require the same response. Such extensive and consistent training on a task leads from performance being under controlled processing to performance becoming automatic (Schneider & Chein, 2003). That is, the participant no longer needs to consciously attend to the stimuli because searching the items has now become an automatic process in which a parallel, rather than a serial, search strategy is being utilized. In contrast, in a varied mapping (VM) situation, responses to the same stimuli can vary from one trial to the next. For example, on one trial the category exemplar "couch" might require a "yes" response while on another trial, it would require a "no" response. Due to this inconsistency, the individual must continue to utilize a serial search and, therefore, the task continues to rely on controlled processing.

In the skill learning studies completed by Schmitter-Edgecombe and colleagues (Schmitter-Edgecombe & Rogers, 1997; Schmitter-Edgecombe & Beglinger, 2001), following extended practice in the VM training conditions (> 1800 trials), CHI participants continued to exhibit slower memory and visual search rates compared to control participants. However, after extensive CM training on the search tasks, both groups showed performance characteristics indicative of automatic process development. That is, similar to controls, the CHI participants demonstrated decreases in reaction time (RT), RT variability, and near-flat slope estimates.

Although both groups showed performance characteristics indicative of automatic process development, the CHI participants were found to be slower at automatizing the memory search task (Schmitter-Edgecombe & Rogers, 1997) but not the visual search task (Schmitter-Edgecombe & Rogers, 1997), compared to controls. This may, in part, be attributed to different components of the tasks being automatized. For a memory search task, the major locus of learning is thought to be the unitization of the memory set (i.e., the memory set of a given number of items becomes one unitized, representative set; Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995; Schneider & Fisk, 1984). For a CM visual search, performance is thought to benefit most from the development of an automatic attention response (AAR) and optimal search strategies (Fisk, Cooper, Hertzog, Anderson-Garlach, & Lee, 1995; Shiffrin, 1988). An AAR refers to a concept wherein the target stimuli automatically attract the participants' attention rather than requiring a controlled process to direct attention. This is because the attention-calling strength of the target stimuli has increased while that of the distractor stimuli has decreased. The development of an AAR represents stimulus-specific learning because automaticity within this type of learning is contingent upon the specific stimuli utilized in the given task. The development of optimal search strategies represents task-specific learning because the general demands of the task (e.g., using the keypad, pressing the appropriate keys, knowing where in the visual display to look for the stimuli, etc.) are learned (Batsakes & Fisk, 2000; Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995). Changing the specific stimuli will greatly affect performance for stimulus-specific but not task-specific skills. By employing the use of a reversal condition (i.e., previous targets become distractors and previous distractors become targets) and a new CM condition (i.e., new targets and distractors are employed) in a visual search task, Schmitter-Edgecombe and Beglinger (2001) were able to show that individuals with a CHI had successfully developed both a stimulus-specific AAR and task-specific optimal search strategies, respectively.

An important question that remains unanswered by previous studies is that of skill retention. Specifically, do those with a CHI retain stimulus-specific and task-specific skills at a level comparable to controls when such processes are not recurrently in use, or is there a difference in the level of skill decay between individuals with a CHI and neurologically healthy individuals? Research regarding the retention of automatic processes of skill learning has mainly been conducted in neurologically healthy populations. In a series of experiments, Fisk and colleagues found that younger adults were able to retain stimulus-specific and task-specific skills up to 16 months post-training (Fisk, Hertzog, Lee, Rogers, & Anderson-Garlach, 1994; Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995). This contrasts with their findings amid neurologically healthy older adults who exhibited a significantly larger level of decay for stimulus-specific skills than younger adults, while displaying a comparable level of retention for task-specific skills (Batsakes & Fisk, 2000; Fisk & Hodge, 1992; Fisk, Hertzog, Lee, Rogers, & Anderson-Garlach, 1994; Fisk, Cooper, Hertzog, & Anderson-Garlach, 1995). These researchers argued that the results of such retention studies depend primarily on what type of skill is being assessed: stimulus-specific or task-specific skills. According to Fisk and colleagues (1994), young adults tend to develop *both* an AAR and optimal search skills in visual search tasks. In contrast, older adults develop only general, task-specific abilities. They do not develop an AAR that would allow them to retain stimulus-specific skills (Fisk, Hertzog, Lee, Rogers, & Anderson-Garlach, 1994).

As discussed earlier, using a semantic category visual search paradigm, previous research in our laboratory has demonstrated that individuals with a CHI successfully develop both stimulus-specific and task-specific skills at a level comparable to controls. In the present study, CHI and control participants from the earlier study (Schmitter-Edgecombe & Beglinger, 2001) were retested following a long-term retention interval (i.e., 5 or 10 months). The level of task-specific and stimulus-specific skill retention was examined by having participants complete the visual search task in a Retention New CM condition and a Retention CM condition, respectively. In the Retention New CM condition, two new categories were used as targets and distractors, while all other task requirements remained the same as during initial training. In the Retention CM condition, both the task requirements and the specific stimuli categorized as targets and distractors were identical to those of the initial training phase. The use of the Retention New CM condition allowed us to examine the level of retention for general task-specific skills without contamination from stimulus-specific skill learning, while the use of the Retention CM condition allowed us to examine the level of retention for stimulus-specific skills.

We hypothesized that CHI participants would show no more decay of stimulus-specific skills than that demonstrated by control participants. This prediction is based upon previous findings in the CHI population which suggest that automatic processes developed prior to injury typically remain intact at one year post-injury (e.g., Schmitter-Edgecombe, Marks, & Fahy, 1993; Schmitter-Edgecombe & Nissley, 2000; Vakil, Blachstein, & Hoofien, 1991), and new automatic processes can be developed post-injury at a level comparable to normal controls (Schmitter-Edgecombe & Rogers, 1997; Schmitter-Edgecombe & Beglinger, 2001). Generating a solid hypothesis related to the retention of general, task-specific skills is more difficult because, to date, research on the long-term rate of forgetting in CHI populations remains sparse. Previous studies that have examined this issue have utilized shorter retention intervals ranging from 30 minutes to six weeks (e.g., Hillary et al., 2003 & Kapur et al., 1996). In general, however, the research on the rate of memory decay in CHI populations has found that significant differences between CHI and normal controls can be curtailed if differences in *initial* learning and acquisition for the material are controlled (Hillary et al., 2003; DeLuca, Schultheis, Madigan, Christodoulou, & Averill, 2000; Carlesimo, Sabbadini, Loasses, & Caltagirone, 1997). We hypothesized that if this is the case, then the CHI and control participants should display comparable levels of general, task-specific skill retention as well.

CHAPTER TWO

RESEARCH DESIGN AND METHODOLOGY

Participants

Participants were recruited from a sample of 18 severe CHI individuals (15 males, 3 females) and 18 matched controls who participated in a previous study by Schmitter-Edgecombe and Beglinger (2001), which investigated skill acquisition and automatic process development following a severe CHI. Eight CHI participants and 6 controls participated in the 5-month retention testing session, while 9 CHI participants and 4 controls participated in the 10-month retention testing session. This resulted in a sample of 17 CHI participants and 10 control participants in the retention phase of this study. The one CHI individual that did not participate initially agreed but missed his appointment and could not be rescheduled. The non-returning control participants either could not be located (n = 2), did not respond to attempted solicitations (n = 4), or failed to attend scheduled appointments (n = 2).

Severity of the CHI was determined during the original study (Schmitter-Edgecombe & Beglinger, 2001). Specifically, participants were considered to have suffered a severe CHI if review of medical records revealed a coma duration of greater than 48 hours (n = 1), or a depth of coma (as measured by the Glasgow Coma Scale) of 8 or less (n = 13). In those cases where medical records were unattainable (n = 1) or the depth and/or duration of coma were unclear from medical records (n = 2), participants were classified as having suffered a severe CHI if both the participant and a significant other reported a coma duration of greater than 48 hours and a period of posttraumatic amnesia (PTA) lasting at least 14 days. All retention CHI participants self-reported a coma duration of greater than 48 hours (M = 29.70 days, SD = 27.14); 67% of these participants reported a coma duration of greater than one week, and 52% reported a coma duration of greater than three weeks. The self-reported duration of PTA was also 14 days or greater for all retention CHI participants (*M* = 83.88, *SD* = 82.55); 82% reported a PTA duration of more than three weeks, and 41% reported a PTA duration of more than nine weeks.

Cause of injury for a majority of the CHI retention participants (*n* = 15) was a motor vehicle accident, while the remaining two injuries were the result of a fall of three meters or greater. To rule out developmental effects, CHI participants were at least 15 years of age at the time of injury and less than 55 years of age at time of initial testing. To avoid the possible influence of spontaneous recovery, all CHI participants were initially assessed at least one year post-injury (range 2-27 years). Eighty-eight percent were more than three years post-injury at the time of retention testing, and 41% were more than 10 years post-injury (*M* = 10.91, *SD* = 8.64). Other exclusion criteria included: a prior history of non-CHI-related neurological disorders (e.g., stroke, attention-deficit hyperactivity disorder, etc.); a prior history of treatment for substance abuse; a prior history of multiple CHIs; a Snellen ratio of less than .50 (measured at a distance of 45 cm); a reading or comprehension impairment; a visual field deficit that would impair viewing of a computer screen; an impairment in the ability to respond with an upper limb during assessment; and a Dementia Rating Scale score below 122. All participants received monetary compensation and parking expenses for participating in both the initial learning and retention phases of the study.

Demographic and cognitive measures collected during the initial training sessions were analyzed for group differences between retention participants. As can be seen in Table 1, analyses of demographic variables revealed no significant differences between returning CHI and returning control participants in age, $t\ (25) = .52$, $p > .05$, education, $t\ (25) = .92$, $p > .05$, mother's occupation, $t(25) = 1.27$, $p > .05$, and father's occupation, $t(25) = -.14$, $p > .05$. Furthermore, an estimate of premorbid intellectual functioning derived using the Barona formula (Barona, Reynolds, & Chastain, 1984) indicated that the returning CHI ($M = 105$, $SD = 3.90$) and returning control ($M = 106$, $SD = 8.99$) participants had highly comparable premorbid intellectual abilities, $t(25) = -.65$, $p > .05$.

Consistent with the findings from the Schmitter-Edgecombe and Beglinger study (2001), the control group performed significantly better than the CHI group on tests assessing verbal learning (California Verbal Learning Test; Delis, Kramer, Kaplan, & Ober, 1987), category fluency (animal names), visual memory (Wechsler Memory Scale-Revised, Wechsler, 1987), verbal memory (Wechsler Memory Scale-Revised, Wechsler, 1987), and processing speed (Symbol Digit Modalities Test; Smith, 1991). These findings indicated that the CHI participants were experiencing residual cognitive deficits that are typical following a severe CHI. Group performances did not differ on cognitive tests assessing short-term memory span (Digit Span subtest from the Wechsler Adult Intelligence Scale-Revised; Wechsler, 1981) and working memory span (Alphabet Span Task; Craik, 1986), illustrating that any group differences found during the initial training and retention studies could not be attributed to disproportionate span capacities between the two groups.

Equipment.

Psychological Software Tools' Micro Experimental Laboratory (MEL) was used to program the experiment, which was presented on IBM-compatible portable computers. The computers presented stimuli, collected responses, and controlled visual display presentation timing.

Initial Training.

Initial training (Schmitter-Edgecombe & Beglinger, 2001) consisted of nine 60-min to 120-min sessions. Neuropsychological testing data and demographic information were collected during the first (Session 1) and final (Session 9) testing sessions. Sessions 6 through 8 involved varied mapping training and will not be discussed further, as it bears no relevance to the current study. Sessions 2 through 4 consisted of CM training. In Session 2, 180 practice trials were completed to allow participants to become familiar with the testing procedures, response keys, and the laboratory environment. Then, for Sessions 2 through 4, participants completed a total of 1,200 experimental trials per day. In the CM condition, the targets (e.g., Trees) never appeared as distractors and the distractors (e.g., Vehicles) never appeared as targets. To ensure that all participants understood how each category and its respective words were defined, participants were presented with a list of the categories and words prior to beginning the task at every session. Session 5 was a transfer session in which participants first received 300 trials of the Trained CM condition, followed by 300 CM Reversal trials, 300 New CM trials, and ended the session with another 300 trials of the Trained CM condition. In the CM Reversal trials, the roles of the previously Trained CM condition targets and distractors were reversed. In the New CM condition, two new categories were combined into a new CM condition. Assessment of the development of an AAR was conducted by comparing performances in the transfer conditions to the Trained CM condition.

Stimuli.

In the initial study (Schmitter-Edgecombe & Beglinger, 2001), stimulus set items were selected from a group of 12 non-overlapping semantic categories which included *Body Parts,* *Beverages, Articles of Furniture, Musical Instruments, Trees, Earth Forms, Weapons, Animals, Building Parts, Vehicles, and Clothing* (Battig & Montague, 1969; Collen, Wickens, & Daniele, 1975). Each category contained six words which were four to six letters in length and were deemed as having a high association to the respective category. For each participant, two categories were presented in the CM training condition (one as a target category and one as a distractor category), two categories were presented in the New CM condition (one as a target category and one as a distractor category), and five categories were presented in the VM condition (serving interchangeably as target or distractor categories). The remaining two categories were presented in this follow-up retention study in a new CM condition (one as a target and one as a distractor), which will be referred to as the Retention New CM condition. In addition, the original two categories used for each participant in the CM training condition were presented in this follow-up retention study, which will be referred to as the Retention CM condition. The categories in the initial study (Schmitter-Edgecombe & Beglinger, 2001) were counterbalanced across participants by a partial Latin square. All stimuli were presented in upper case letters at a viewing distance of 45 cm with the entire display extending 2.4° in height and 6.0° in length.

General Procedure.

Each experimental trial began with a category label appearing on the left side of the screen for a maximum of 20 seconds. After reading the category label, the participant then pressed the space bar with their non-dominant hand to initiate the trial. The category label was then replaced by a series of X's and a focus cross appeared in the center of the computer screen. After 500 ms, the display set was presented around the focus cross. Each display set consisted of up to four words presented in two rows with two words in each row, forming a rectangle. Two, three, or four words were presented in each display set, and for those trials containing less than four words, a placeholder was used that always consisted of the same five characters (#@$&%). Placeholders were used to ensure that display size load effects were the result of semantic load and not lateral masking. At the presentation of each display set, the participant was to press a key on a numeric keypad that corresponded to the location of the word that was the correct category exemplar (e.g., a key labeled "UL" corresponded with the upper left location of the display, a key labeled "LR" corresponded with the lower right location of the display, etc.). The participant's response time was displayed on the screen following a correct response, while a tone and error message with the correct answer was displayed following an incorrect response (see Figure 1). Participants were required to maintain accuracy rates between 93% and 97% and the computer provided feedback about their accuracy rates after the completion of each block. Each block consisted of 60 trials with 20 trials per set size. Rest breaks were offered to each participant in between each block.

Retention Testing Procedure.

In order to examine both task-specific and stimulus-specific skill retention during the retention testing phase, all participants completed 300 trials in a Retention New CM condition, followed by 900 trials in the originally trained (Retention) CM condition (Schmitter-Edgecombe & Beglinger, 2001). The Retention New CM condition was administered prior to the Retention CM condition to allow for the examination of task-specific skills without contamination of stimulus-specific skills. In the Retention New CM condition, the participant was required to perform the same task as the Trained CM condition, but with new categories, thus revealing the extent to which general, task-specific skills were retained. In the Retention CM condition, the same categories and their respective category exemplars as the Trained CM condition were utilized in order to examine stimulus-specific skills. Before the retention session, each participant was asked to recall the initial CM target category on which he or she was previously trained extensively. Thirty-five percent of the CHI participants and 27% of the controls could accurately recall the trained category.

CHAPTER THREE

ANALYSIS

Because no long-term skill retention studies have been conducted in the CHI population, we initially planned to not only examine differences in overall skill retention between the CHI and control samples, but also to explore skill retention at a 5-month interval for approximately half of the participants and a 10-month interval for the other half. Because only 10 of the control participants returned for retention testing at either the 5-month (n = 6) or the 10-month (n = 4) retention interval, we were unable to analyze potential differences between the retention intervals for this group. For this reason, as well as the fact that our primary question related to differences in overall skill retention between the two groups, data were collapsed across the retention intervals for our initial set of analyses.

To ensure that our returning control sample was representative of the original control sample, we began by comparing the original CM training data for the returning and non-returning control participants. Similar analyses were not conducted for the CHI group because all but one participant returned for retention testing. Next, we compared the CM training performances of the returning control participants and the returning CHI participants to ensure that our findings were similar to those obtained with the original sample for skill learning and AAR development. Then, to examine potential differences between the CHI and control participants in the level of overall skill retention, we computed and compared stimulus-specific savings and task-specific loss scores. Finally, the level of skill retention within the CHI sample was examined in relation to the 5-month and 10-month retention interval to evaluate skill retention at different time points.

Original CM Training

Analyses of data from the three initial CM training sessions were conducted by grouping the 60 sets of trials into blocks of five (300 trials per block) and averaging across the three set sizes (set size 2, 3, & 4); this resulted in one mean RT per participant for each of the 12 blocks. The within-subjects independent variable was Practice (Blocks 1-12 of original CM training) or Transfer Condition (New CM & CM Reversal), while Group (non-returning controls and returning controls; returning CHIs and returning controls) was a quasi-experimental variable. Reaction time, accuracy, and proportional difference scores were the dependent variables[1].

Returning and Non-returning Controls

Reaction Time Data. First, analyses were conducted to determine if differences in initial skill learning existed between the returning (n = 10) and non-returning ($n = 8$) control participants. A Group (returning controls & non-returning controls) X Practice (Blocks 1-12 of original CM training) mixed-model ANOVA conducted on the RT data revealed no significant main effect for Group, $F < 1$. The returning ($M = 735.63$, $SD = 25.50$) and non-returning ($M = 764.88$, $SD = 28.51$) control participants displayed similar overall RTs. In addition, although there was a significant main effect of Practice, F (11, 176) = 28.43, $MSE = 56013.07$, $p < .01$, there was no significant Group X Practice interaction, $F < 1$. As can be seen in Figure 2, both the returning and non-returning control participants demonstrated similar decreases in RT from block 1 (returning controls: $M = 848.66$, $SD = 113.48$; non-returning controls: $M = 873.53$, $SD = 81.20$) to block 12 (returning controls: $M = 676.06$, $SD = 103.04$; non-returning controls: $M = 720.81$, $SD = 75.51$) of training.

[1] For several of the repeated measures ANOVAs, the assumption of homogeneity of covariance was violated. In those cases, we further evaluated the data by examining the multivariate statistics. With the exception of finding a significant Practice effect when examining accuracy data for the returning versus non-returning control participants, the results of both analytical techniques revealed an identical pattern of findings. Therefore, we have chosen to present the data using the more conventional univariate statistic.

Accuracy Data. A Group (returning controls & non-returning controls) X Practice (Blocks 1-12 of original CM training) mixed-model ANOVA was also conducted on the accuracy data. The results of this analysis revealed a significant main effect of Group, F (1, 16) = 4.63, MSE = .36, p = .05. Although the overall accuracy rate of the non-returning controls (M = 95.55%) was higher than that of the returning controls (M = 93.68%), both groups successfully maintained their accuracy rate between 93% and 97%. A small decrease in accuracy rate was found with Practice, F (11, 176) = 1.93, MSE = .10, p < .05, however, multivariate tests did not support this finding, p > .05. Importantly, the Group X Practice interaction was not significant, F < 1, indicating that the returning and non-returning controls demonstrated similar changes in accuracy rate with practice from block 1 (returning controls: M = 94.45%, SD = 12; non-returning controls: M = 96.2%, SD = 13) to block 12 (returning controls: M = 92.9%, SD = 17; non-returning controls: M = 94.9%, SD = 19) of training.

Although these findings suggest that the subsample of control participants who returned for retention training was representative of the original control sample, a summary of the returning CHI and returning control participants' performances on the originally trained CM and transfer conditions follows.

Returning CHIs and Returning Controls

Reaction Time Data. A Group (returning CHI & returning controls) X Practice (Blocks 1-12 of original CM training) mixed-model ANOVA on the RT data revealed that search RTs improved with CM training for both groups, but the control group's RT (M = 735.63; SD = 77.32) was consistently faster than that of the CHI group (M = 971.37; SD = 59.30). These findings were supported by the significant main effects of Group, F (1, 25) = 5.85, MSE = 4198930.70, p < .05, and Practice, F (11, 275) = 29.40, MSE = 135237.97, p <.001. The Group

X Practice interaction approached significance, F (11, 275) = 1.77, MSE = 8158.80, p = .06, suggesting that the CHI group demonstrated a larger amount of absolute improvement in response time from the early to final blocks of training compared to the control group (see Figure 3).

Accuracy Data. During CM training, participants in both the returning CHI and returning control groups were able to maintain accuracy rates between 93% and 97% (see Table 2). A Group (returning CHI & returning controls) X Practice (Blocks 1-12 of original CM training) mixed-model ANOVA revealed no significant main effect of Group, $F < 1$, and no significant Group X Practice interaction, $F < 2$. A test of the within-subjects effects suggested that accuracy may have decreased slightly with Practice, F (11, 275) = 2.14, MSE = .13, $p < .05$, but this effect was not supported with multivariate tests ($p > .05$), which is consistent with the previous findings (Schmitter-Edgecombe & Beglinger, 2001).

Transfer Data

Reaction Time Data. Given that both the returning CHI and returning control participants demonstrated significant learning, we then examined AAR development by comparing participants' performances in two transfer conditions (New CM and CM Reversal) to their final level Trained CM performance. In order to analyze the RT data, proportional difference scores were calculated separately for each participant by subtracting the Trained CM RT (final 5 blocks of original CM training) from the New CM RT or CM Reversal RT, and then dividing by the Trained CM RT. If participants develop an AAR, the CM Reversal condition should significantly disrupt performance and lead to longer RTs compared to the New CM condition (Shiffrin & Schneider, 1977). Results of a Group (returning CHI & returning controls) X Transfer Condition (New CM & CM Reversal) mixed-model ANOVA using proportional difference scores revealed a significant main effect for Transfer Condition, F (1, 25) = 40.56, MSE = .50, p < .001, indicating that disruption in performance was greater for the CM Reversal condition (M = .51, SD = .05) relative to the New CM condition [(M = .32, SD = .03); see Figure 4]. The main effect of Group, F < 1, and the Group X Transfer Condition interaction, F < 2, were not significant, indicating that the CHI and control participants did not differ in their level of AAR development.

Accuracy Data. The results of a Group (returning CHI & returning Control) X Transfer Condition (New CM & CM Reversal) mixed-model ANOVA on the accuracy data revealed a significant main effect of Transfer Condition, F (1, 25) = 15.38, MSE = 1.70, p < .01, which was modified by a significant Group X Transfer Condition interaction, F (1, 25) = 5.21, MSE = .57, p < .05. Controls were comparable in accuracy rates for the New CM (M = 94%, SD = 38) and CM Reversal (M = 93%, SD = 39) conditions, but the CHI participants demonstrated higher accuracy rates in the New CM condition (M = 93%, SD = 60) compared to the CM Reversal condition (M = 91%, SD = 90). Overall accuracy rates did not differ between groups, F (1, 25) = 1.16, MSE = .87, p > .05.

Taken together, these findings indicate that both the returning CHI and returning control groups demonstrated comparable levels of stimulus-specific and task-specific skill learning. Given our interest in examining the retention of these skills over time, the results of the analyses conducted on the retention data follows.

Retention Data

Three hundred Retention New CM trials (5 sets of 60) followed by 900 Retention CM trials (15 blocks of 60) were administered at retention testing. Consistent with our analyses of the initial training data, these trials were grouped into blocks (300 trials per block) and then averaged across set sizes (set size 2, 3, & 4) to obtain one mean RT per participant for each block. This resulted in one mean RT and accuracy rate per participant for the Retention New CM condition and three mean RTs and accuracy rates per participant for the Retention CM condition. The analyses that immediately follow utilized only the first mean RT and accuracy rate for the Retention CM condition.

Reaction Time Data. To determine whether participants' retention performances were faster than their performance during the first block of initial learning (i.e., first block of original CM training), a Group (returning CHI & returning controls) X Condition (initial CM training, Retention New CM, & Retention CM) mixed-model ANOVA was conducted on the RT data. Results revealed that the CHI participants (M = 1062.41, SD = 58.88) exhibited significantly slower overall RTs than control participants (M = 810.87, SD = 76.77), F (1, 25) = 6.76, MSE = 1195207.12, $p < .05$. There was also a significant main effect of Condition, F (2, 50) = 11.33, MSE = 106705.65, $p < .01$. Reaction time for the Retention CM condition (M = 870.27, SD = 42.83) was significantly faster than the RT for both the Retention New CM condition (M = 939.28, SD = 50.01), t (26) = 3.74, $p < .01$, and initial CM training (M = 1000.37, SD = 58.59), t (26) = -5.18, $p < .01$, while RT for the Retention New CM condition was significantly faster then the initial CM training, t (26) = -2.16, $p < .05$.

Accuracy Data. A Group (returning CHI & returning controls) X Condition (initial CM training, Retention New CM, & Retention CM) mixed-model ANOVA was conducted on the accuracy data to rule out any potential issues related to speed-accuracy trade-offs. Results revealed no significant main effect of Group, $F < 1$ or Condition, $F < 1$, and no significant Group X Condition interaction, $F < 1$. Accuracy rates were 94%, 95% and 95% for the CHI group and 94%, 95%, and 95% for the control group in the initial CM training, Retention New CM, and

Retention CM conditions, respectively. These results indicated that the CHI and control participants were uniformly accurate within each condition, and accuracy was comparable between all three conditions.

Savings and Loss Scores. In order to examine stimulus-specific and task-specific skill retention across groups, savings and loss scores were computed following the procedure used by Fisk and colleagues (1994). More specifically, a stimulus-specific cost score was computed as the difference between the last block of the original Trained CM condition and the Retention CM condition (final Trained CM – Retention CM). A task-specific savings score was computed as the difference between the first block of the original Trained CM condition and the Retention New CM condition (initial Trained CM – Retention New CM; Fisk et al., 1994). In addition, to account for baseline differences between the CHI and control groups, we also computed proportional stimulus specific loss scores and proportional task-specific savings scores, calculated as the stimulus-specific cost score divided by the last block of the original Trained CM condition [(final Trained CM – Retention CM)/final Trained CM] and the task-specific savings score divided by the first block of the original Trained CM condition [(initial Trained CM – Retention New CM)/initial Trained CM], respectively. Independent-samples *t*-tests on the savings and loss scores were first conducted using the cost scores and then the proportional difference scores.

For the stimulus-specific cost score, no significant difference between the returning CHI (M = -67.66, SD = 93.09) and returning control (M = -93.65, SD = 66.10) groups was found, t (25) = -.77, p > .05, suggesting no difference between the two groups in the amount of loss for stimulus-specific skills. The task-specific savings score analysis also revealed no significant difference between the returning CHI (M = 85.75, SD = 190.48) and returning control (M =

36.43, $SD = 99.20$) groups in the amount of savings for task-specific skills, $t(25) = -.76$, $p > .05$. Analyses utilizing proportional difference scores revealed similar findings. That is, the returning CHI ($M = -.09$, $SD = .10$) and returning control ($M = -.15$, $SD = .09$) groups did not differ significantly on the stimulus-specific loss score, $t(25) = -1.36$, $p > .05$. In addition, no significant difference was found between the returning CHI ($M = .06$, $SD = .16$) and returning control ($M = .03$, $SD = .12$) groups for task-specific savings, $t(25) = -.46$, $p > .05$ (see Figure 5).

It is important to note that the small sample size and large standard deviation values for both skill types could have potentially obscured group differences. However, given that the CHI participants exhibited greater retention of both stimulus-specific and task-specific skills compared to the returning controls, an increase in sample size, which may unearth significant group differences, would not influence the interpretation of the findings; CHI participants would continue to demonstrate greater skill retention compared to controls. More specifically, the returning CHI participants demonstrated an average 9% loss of stimulus-specific skills while the returning control participants demonstrated an average 15% loss. In regards to task-specific savings, the returning CHI participants demonstrated an average 6% savings while the returning control participants demonstrated an average 3% savings. As will be seen in the following section, part of the large variability in skill retention for the CHI group was a factor of some participants completing retention testing at 5 months and some at 10 months.

CHI Retention Interval Exploration. Given that approximately half of the returning CHI participants completed the retention testing at 5 months ($n = 8$) and the other half at 10 months ($n = 9$), we then examined the possibility of differences in stimulus-specific and task-specific skill retention between these intervals for the returning CHI participants. An Independent-samples *t*-test utilizing proportional difference scores indicated a significantly greater loss for stimulus-specific skills after the 10-month retention interval (*M* = -.15, *SD* = .07) compared to the 5-month interval (*M* = -.03, *SD* = .07) in the returning CHI group, t (15) = 3.63, $p < .01$. In fact, the data demonstrated nearly complete savings of stimulus-specific skills for the returning CHI participants at the 5-month retention interval. Although the difference in task-specific savings between the 5-month and 10-month retention intervals did not reach statistical significance, t (15) = 1.54, $p > .05$, the results were in the direction of decreasing task-specific skill retention from the 5-month (*M* = .12, *SD* = .10) to the 10-month (*M* = .01, *SD* = .19) retention interval (see Figure 6). In this case, the data suggested that the 10-month retention CHI group exhibited essentially no task specific savings. Similar analyses were not conducted for the control participants due to a lack of power[2].

Analyses were then conducted to determine if the finding of poorer skill retention at the 10-month compared to the 5-month retention interval within the retention CHI group was due to differences in initial skill development. A returning CHI Group (5-month & 10-month) X Practice (Blocks 1-12 of original CM training) mixed-model ANOVA conducted on the initial RT data revealed a significant main effect of Practice , F (11, 165) = 28.12, *MSE* = 141949.84, $p < .01$, and a significant Group X Practice interaction, F (11, 165) = 3.79, *MSE* = 19115.77, $p < .01$. There was no significant main effect of Group, $F < 2$. As can be seen in Figure 7, break-down of the interaction suggested that those CHI participants that returned at the 5-month interval showed a bigger decrease between block 4 and block 5 of original CM training (*M* = 222.16, *SD* = 190.82), which is the end of Day 1 of CM training and the beginning of Day 2 of CM training, respectively, than did those who returned for the 10-month interval (*M* = 63.65, *SD*

[2] Although a lack of power prohibited us from statistically examining differences in skill retention between the 5-month and 10-month retention intervals for returning control participants, the mean proportional difference scores showed decreases in stimulus-specific savings from the 5-month (*M* = -.12, *SD* = .11) to the 10-month (*M* = -.18, *SD* = .06) retention intervals and decreases in task-specific skill retention from the 5-month (*M* = .06, *SD* = .10) to the 10-month (*M* = -.003, *SD* = .14) retention intervals.

= 63.38), t (15) = 2.36, $p < .05$. Despite this difference, both groups demonstrated a similar overall decrease in RT from block 1 to block 12 of training. More specifically, the 5-month group demonstrated decreases from CM training block 1 to CM training block 12 of 276.28 ms, which translates into a 22% decrease in RT, while the 10-month group demonstrated a change from CM block 1 to CM block 12 of 222.71 ms, which translates into a 21% decrease in RT. Thus, both groups demonstrated comparable rates of improvement from the beginning to the end of original CM training.

To examine potential group differences in the development of an AAR, a retention CHI Group (5-month & 10-month) X Transfer Condition (New CM & CM Reversal) mixed model ANOVA was conducted using proportional difference scores. The results revealed a significant main effect of Transfer Condition, F (1, 15) = 26.38, MSE = .22, $p < .01$, and a significant Group X Transfer Condition interaction, F (1, 15) = 5.73, MSE = .05, $p < .05$. While both groups exhibited longer RTs in the CM Reversal condition compared to the original New CM condition, indicating the development of an AAR, returning CHI participants in the 5-month group showed greater disruption than those in the 10-month group. However, there was no significant main effect of Group, $F < 1$. These results suggested that the 5-month group may have developed a stronger AAR than the 10-month group during initial training (see Figure 8), possibly contributing to the greater skill loss found for the CHI participants tested at the 10-month retention interval.

To evaluate whether differences in injury characteristics, demographic variables, or neuropsychological variables contributed to the findings of differing levels of skill loss between the 5-month and 10-month retention intervals, Independent Samples t-tests on the variables reported in Table 1 and injury variables were conducted. Because a large number of variables were examined, a more conservative *p*-value of .01 was used to interpret statistical significance. Results revealed no significant differences between the CHI participants returning at the 5-month and the 10-month retention intervals for any injury characteristics, demographic variables, or neuropsychological variables, $t < 2$, $p > .05$ (see Table 3). These findings suggested that none of the above-mentioned variables likely contributed to the finding of greater skill loss for the 10-month CHI group compared to the 5-month CHI group.

Lastly, we examined the 5-month and 10-month CHI groups' level of re-learning. Consistent with the stimulus specific savings analysis, a Paired-samples *t*-test comparing the first block (i.e., the first 300 trials) of the Retention CM condition (M = 1004.65, SD = 362.88) with the final block of the original CM training (M = 999.32, SD = 442.39) revealed no significant differences for the 5-month retention CHI participants, $t\ (7) = .17$, $p > .05$. In contrast, the 10-month retention group showed a significant difference between the first block of the Retention CM condition ($M = 940.76$, $SD = 133.35$) and the final block of the original CM training ($M = 817.69$, $SD = 128.29$), indicating that this group began the retention trials at a rate that was significantly slower than their final-level performance on initial CM training, $t\ (8) = 6.61$, $p < .01$. Similarly, a Paired-samples *t*-test comparing the final block (i.e., last 300 trials) of the Retention CM condition ($M = 1003.81$, $SD = 464.21$) with the final block of the original CM training ($M = 999.32$, $SD = 442.39$) revealed no significant differences for the 5-month group, $t\ (7) = .20$, $p > .05$, while a significant difference was found between these blocks [Final block of original CM training: ($M = 817.69$, $SD = 128.29$); final block of Retention CM condition: ($M = 887.60$, $SD = 140.17$)] for the 10-month group, $t\ (8) = 4.30$, $p < .01$. As can be seen in Figure 9, although the 10-month CHI group demonstrated improvement in performance throughout the retention trials (i.e., over a total of 900 trials), unlike the 5-month group, they were never able to reach their final-level performance of original CM training.

CHAPTER FOUR

DISCUSSION

We were interested in whether individuals who had sustained a severe CHI could retain task-specific and stimulus-specific skills over a long-term retention interval (i.e., 5 or 10 months) at a rate comparable to controls. In an earlier skill learning study, which employed a CM visual search task, we found that individuals with a CHI were able to develop both general, task-specific skills, and an automatic attention response (AAR; i.e., a stimulus-specific skill) at a level comparable to controls (Schmitter-Edgecombe & Beglinger, 2001). In the current study, 17 of the original 18 CHI participants and 10 of the original 18 control participants returned for testing to determine the level of long-term retention for these two types of skills.

Analyses of the original CM training data revealed that the subsample of control participants that returned for retention testing was representative of the original sample. In addition, comparisons between the returning CHI and returning control participants on the original CM training and transfer data replicated those found in the original training study with the entire sample (Schmitter-Edgecombe & Beglinger, 2001). More specifically, the RT performances of both groups improved with practice and both groups demonstrated a comparable level of AAR development.

In the current study, we were therefore able to examine long-term retention for a visual search skill that was acquired to a similar level of performance for both the returning CHI and returning control participants. To date, there has been a dearth of investigations into long-term skill retention, in a CHI sample and in the neurological literature in general. We found that both the returning CHI and returning control participants demonstrated comparable levels of skill retention when the data were collapsed across the 5-month and 10-month retention intervals. Specifically, both difference and proportional difference scores revealed that the returning CHI and returning control participants were comparable in their levels of loss for stimulus-specific skills and savings for task-specific skills. These findings are unique in suggesting that once an automatic process has been developed, individuals with a CHI are able to retain these skills over a long-term period at a level comparable to normal controls when continued practice has not been implemented.

In an earlier study that examined long-term skill retention with healthy younger and older adults, Fisk and colleagues (1994) reported that their sample of older adults initially developed general, tasks-specific skills, but were unable to develop an AAR (stimulus-specific skills) in a visual search task. For this reason, the older adults demonstrated retention levels comparable to younger adults only for task-specific skills and not stimulus-specific skills, which require the prior development of an AAR (Fisk et al., 1994). In contrast, we found evidence indicating that our CHI participants initially develop both skills in a visual search situation similar to control participants (Schmitter-Edgecombe & Beglinger, 2001). The current findings also demonstrated that the CHI participants were able to retain both of these skills at a level comparable to controls.

Fisk and colleagues (1994) also reported a remarkable amount of skill retention over a 16-month interval in their sample of neurologically healthy younger and older adults. Specifically, their findings demonstrated a stimulus-specific skill loss of only 28% and 38% for young and older adult participants, respectively, over a 16-month interval. Using a similar method of data interpretation, our findings also show an impressively small amount of average skill loss (i.e., 9% for CHIs and 15% for controls) across a shorter 5 to 10 month retention interval. It should be noted, however, that Fisk and colleagues' (1994) method of interpretation may be misleading given that stimulus-specific loss was computed without taking into consideration the maximum savings possible based on initial skill development. After taking the maximum savings possible into consideration (i.e., skill gain from the beginning of CM training to the end of CM training), our data indicate that the CHI participants demonstrated an average 9% loss of stimulus-specific skills out of a 27% possible average loss while the control participants demonstrated an average 15% loss out of a 26% possible average loss. This interpretation indicates a greater overall loss for stimulus-specific skills than originally believed.

Although Fisk and colleagues (1994) did not report detailed data for task-specific savings in their study, examination of their graph suggests that their older adults showed a trend towards saving more task-specific skills (approximately 23-24%) than their young adults (approximately 18-19%). Similarly, our CHI participants demonstrated a trend towards greater savings of such skills (average 6%) when compared to our control participants (average 3%). Although this difference was not statistically significant in either study, it is interesting to note. For Fisk and colleagues' (1994) sample, one possible explanation could be that the older adults are making more of an effort on this aspect of the task because they are not able to perform at the same level as the younger adults on stimulus-specific aspects of the task. However, given that the CHI participants in this study were able to acquire both stimulus-specific and task-specific skills at a level comparable to controls, the cause of this pattern in our sample is unclear. In addition, it remains unclear as to what caused the large difference between our participants and Fisk and colleagues' participants (1994) in the amount of task-specific skill retention. The most likely explanation for the difference is that Fisk and colleagues (1994) administered the Retention CM condition prior to the Retention New CM condition while our participants received these two conditions in the reverse order. By beginning with the Retention CM condition to measure stimulus-specific skills, Fisk and colleagues (1994) may have inadvertently allowed for participants to practice, or re-train on, task-specific skills, thus leading to enhancement of task specific skills by the time the Retention New CM condition was administered.

Despite the lack of available information on the long-term retention of automatic skills in the neurological literature, the current findings are consistent with the more general findings on the rate of forgetting in CHI samples. In general, the literature suggests that differences in the rate of forgetting or memory decay between individuals with a CHI and controls are insignificant once differences in the initial learning and acquisition for the material are controlled (Hillary et al., 2003; DeLuca, Schultheis, Madigan, Christodoulou, & Averill, 2000; Carlesimo, Sabbadini, Loasses, & Caltagirone, 1997). The current findings support this by showing similar levels of retention for a skill that was initially learned to a comparable level for the CHI and control groups.

An interesting pattern that emerged in our data for stimulus-specific skill retention suggested that CHI participants are able to retain significantly more of this skill at the 5-month interval compared to the 10-month interval. Although not statistically significant, a similar trend emerged with task-specific skill retention as well. In terms of stimulus-specific skill savings, the 5-month group showed essentially no loss of such skills at retention testing, while the 10-month group never fully returning to their trained performance. Analyses revealed that this difference was not the result of differences in injury characteristics, demographic variables, or neuropsychological variables. Examination of the data also indicated that the 5-month CHI group initially developed a stronger AAR than the 10-month CHI group. However, individual data examination revealed that even when removing those participants in the 10-month CHI group who did not develop and AAR or who developed a weak AAR, the group's mean stimulus-specific loss score remained essentially the same, indicating that the passage of time may be the most significant contributor to this pattern of data. As no other studies examining long-term skill retention in a CHI population have been conducted to date, future research will be needed to further examine this issue. In general, it appears that remediation techniques that involve visual information and rely on automatic skill development may benefit from "booster" or re-training sessions following initial training, especially if the skill is not continuously being utilized.

The current research also increases the generalizability of other studies' findings to a longer retention interval because most of the studies conducted thus far have utilized much shorter retention intervals (e.g., Hillary et al., 2003; DeLuca, Schultheis, Madigan, Christodoulou, & Averill, 2000; Carlesimo, Sabbadini, Loasses, & Caltagirone, 1997). Also, these findings increase the generalizability to different stimuli than those that have been utilized previously (e.g., word list learning and line drawing learning) and also to a different type of processing than what has been previously examined (i.e., controlled processing). Further research will need to be conducted in order for these findings to generalize to populations with broader neurological insults and to other skill learning tasks.

The relatively small control sample size likely introduced the possibility of power issues for our analyses. Although such a limitation can be overcome by simply increasing the sample size, studies examining skill learning and skill retention face numerous barriers in regards to obtaining adequate power. The repeated testing sessions required for extensive skill training and the recruiting of participants to return after long retention intervals proves to be a significant impediment to conducting this type of research. One way to overcome such issues may be to recruit a larger sample size at initial training, but this can prove problematic when dealing with a population as specific as severe CHIs.

In summary, the results of this study are important for several reasons. Very few skill learning studies have been conducted in the neurological literature. Also, this data is unique in the fact that such a long-term retention interval (i.e., 5 or 10 months) has never been utilized in the CHI population to our knowledge. Previous studies examining long-term forgetting rates in a severe CHI population ranged from intervals of 30 minutes to 6 weeks (e.g., Hillary et al., 2003 & Kapur et al., 1996). Also, and most importantly, despite differences in RT performance, CHI participants not only developed task-specific and stimulus-specific skills at a rate comparable to controls, but they were able to *retain* these skills at a rate comparable to controls without continued practice. Together, these findings have important implications for cognitive remediation techniques following a severe CHI. Specifically, breaking down complex cognitive skills and consistently training individuals on smaller components of the task in order to develop automatic processes is a worthwhile strategy as such skills are likely to be retained over a long-term interval, perhaps more so with follow-up "booster" or re-training sessions.

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APPENDIX

Table 1. Demographic data and neuropsychological variables for the CHI and control groups

	CHIs			Controls		
Variables or test	***M***	***SD***	***N***	***M***	***SD***	***N***
Age (years)	34.12	9.41	17	32.18	9.43	10
Education (years)	13.82	1.91	17	13.20	1.23	10
Occupation status[a]						
Mother	3.12	1.99	16	2.11	1.76	9
Father	2.14	1.35	14	2.22	1.30	9
Barona FSIQ Estimate	104.86	3.90	17	106.48	8.99	10
CVLT Trials 1-5[b]	49.68	10.31	16	59.80*	6.44	10
WMS-R[b]						
Visual Reproduction I	34.82	3.97	17	37.70*	2.31	10
Visual Reproduction II	30.82	6.97	17	36.00*	3.23	10
Logical Memory I	19.68	7.83	16	31.70*	8.24	10
Logical Memory II	15.06	7.97	16	29.70*	7.74	10
Category Fluency[b]	18.31	5.47	16	23.40*	5.03	10
SDMT[b]						
Written	41.59	11.57	17	57.00*	7.33	10
Oral	50.19	15.12	16	63.20*	7.60	10
WAIS-R[b] Digit Span Subtest	15.12	3.15	16	17.60	3.71	10
Alphabet Span Test[c]	3.90	.82	16	4.50	.52	10

Notes. CHI = Closed-head injury; CVLT = California Verbal Learning Test; WMS-R = Wechsler Memory Scale-Revised; WAIS-R = Wechsler Adult Intelligence Scale-Revised.

[a]Occupational status of each participant's parents was scored on a 6-point Occupational Scale (WAIS-R; Wechsler, 1981; 1 = *professional and technical workers*; 6 = *not in the labor force*).

[b]Raw scores.

[c]Age-corrected score.

**p* < .05.

Figure 1. Example of the visual search task experimental trials for a correct consistent mapping (CM) training response and an incorrect CM training response.

Semantic Category
Search Task

	CM Training	**CM Training**
Category Label (left side; up to 20 sec)	ANIMAL	ANIMAL
	⇩	⇩
500 ms Fixation Cross (in center)	XXXXX +	XXXXX +
	⇩	⇩
Visual Display (around fixation cross; 2, 3, or 4 items)	GOAT PINE PALM #@$&%	#@$&% WOLF PALM #@$&%
	⇩	⇩
Keyboard Response	Upper Left Key	Lower Left Key
	⇩	⇩
Feedback (RT or error message)	424 milliseconds	ERROR, correct response was WOLF

Figure 2. Mean reaction time data plotted as a function of consistent mapping (CM) practice for the returning and non-returning controls. Each block represents a total of 300 trials collapsed across set sizes 2, 3, & 4.

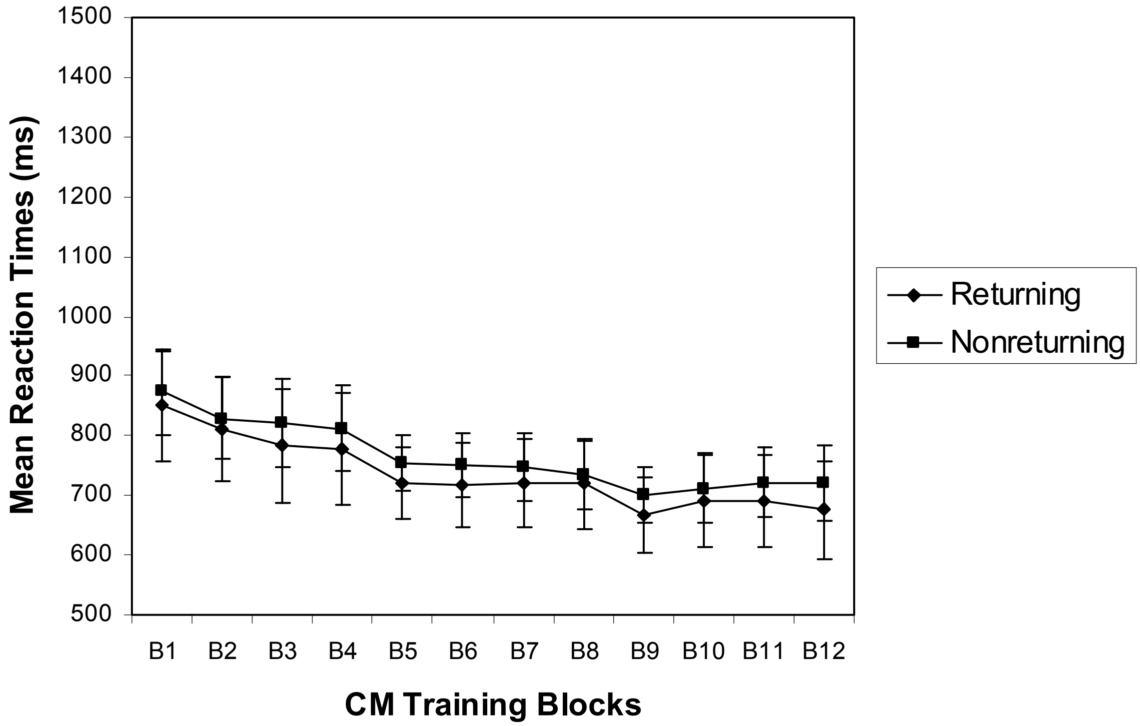


Figure 3. Mean reaction time data plotted as a function of consistent mapping (CM) practice for the returning controls and the returning closed-head injury (CHI) groups. Each CM training block represents a total of 300 trials collapsed across set sizes 2, 3, & 4.

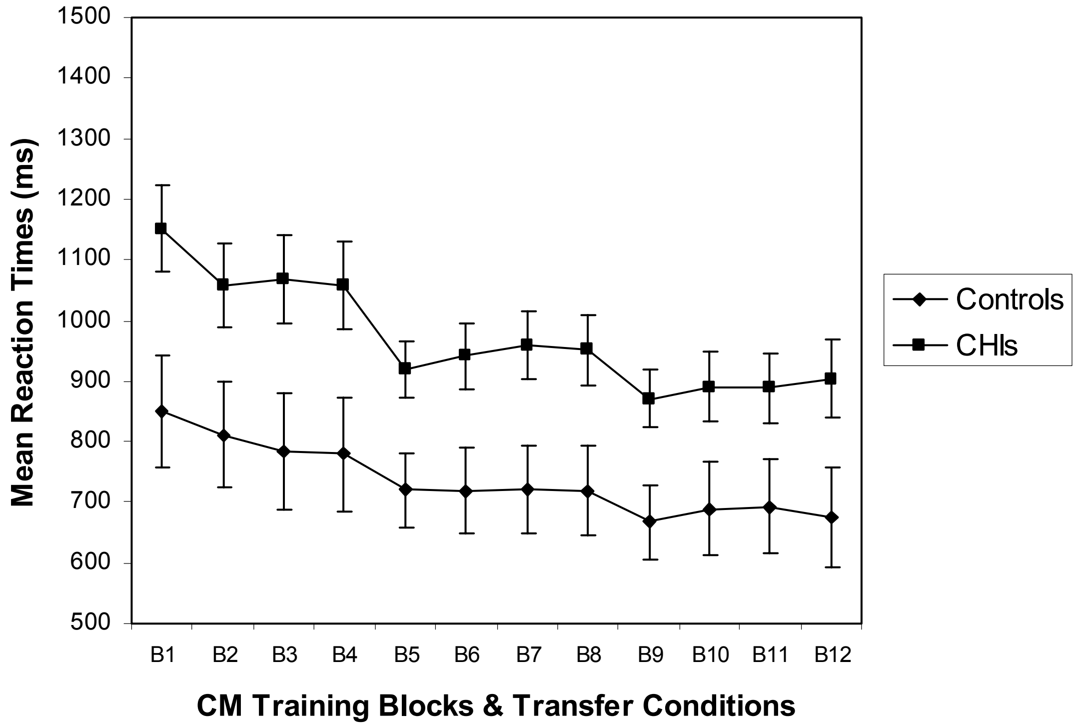


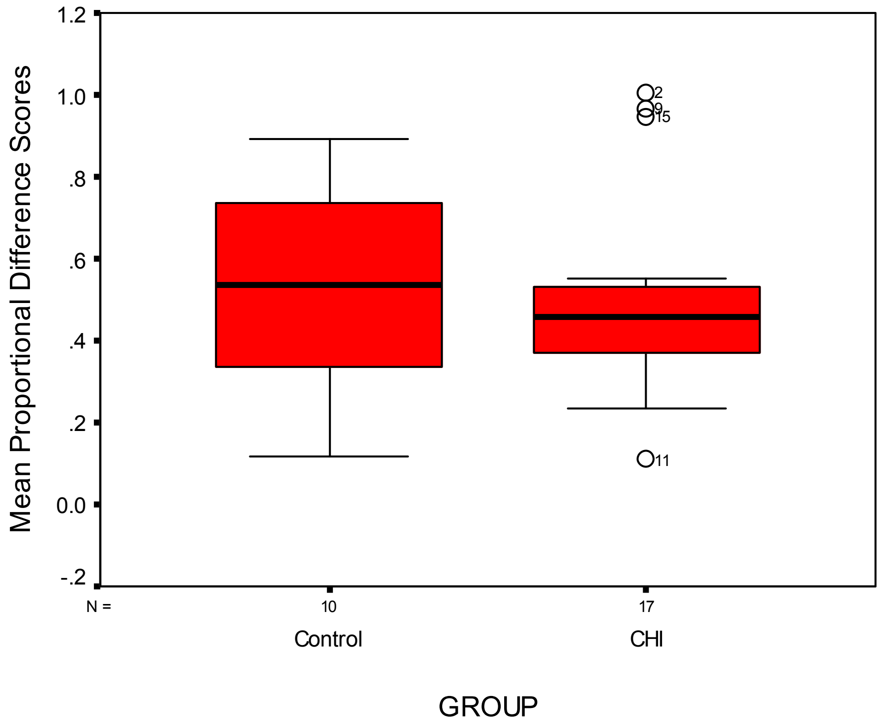
Table 2. Percentage accuracy rates for returning controls and returning CHIs by block for the CM training condition.

CM Training Blocks

Groups	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Returning Controls	94	94	95	94	94	95	94	94	93	94	95	93
Returning CHIs	95	95	94	94	94	94	95	94	94	94	94	94

Figure 4. Mean proportional difference scores for the CM Reversal (4a) and original New CM condition (4b) for the returning control and returning CHI participants.

4a.



4b.

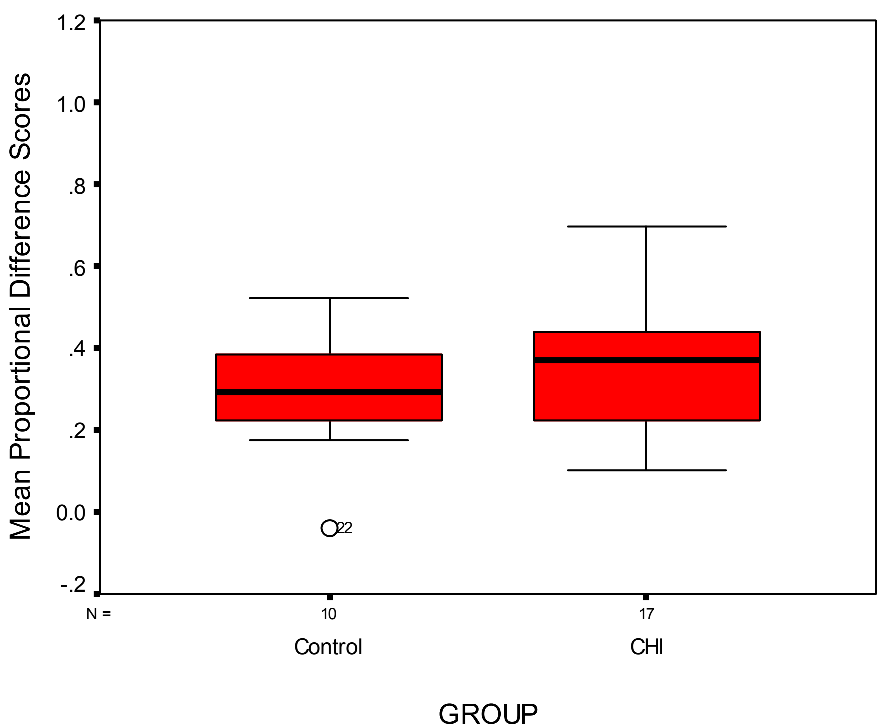
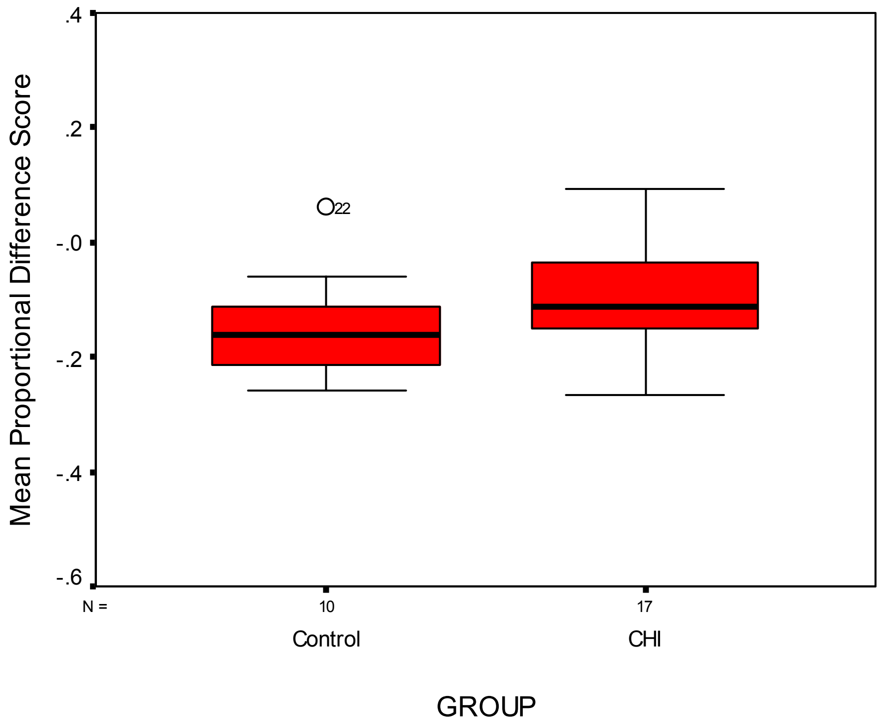


Figure 5. Mean proportional difference score data for Stimulus-specific loss (5a) and Task-specific savings (5b) for the returning control and returning CHI participants.

5a.



5b.

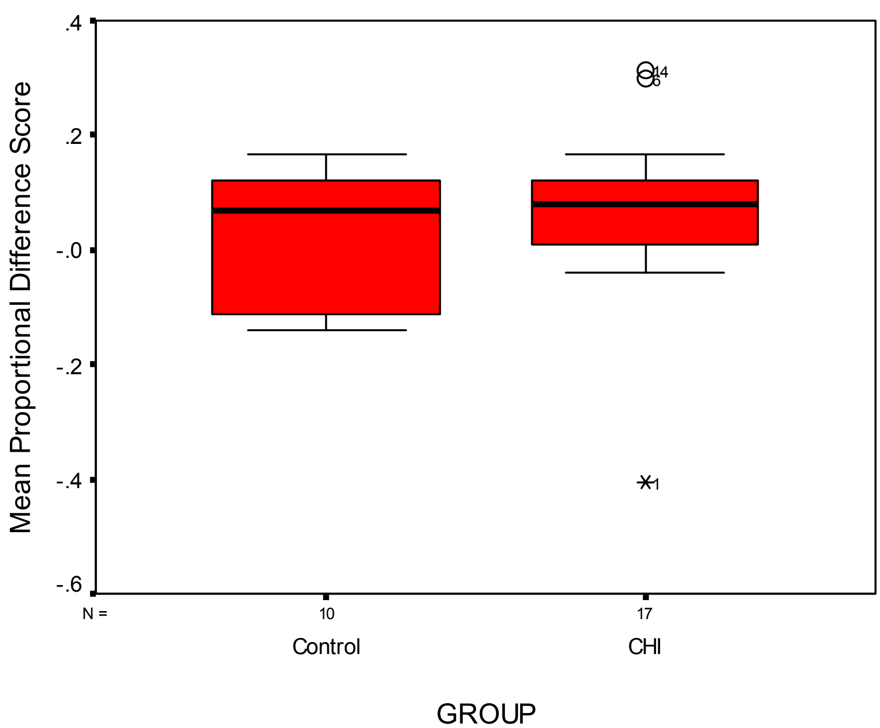
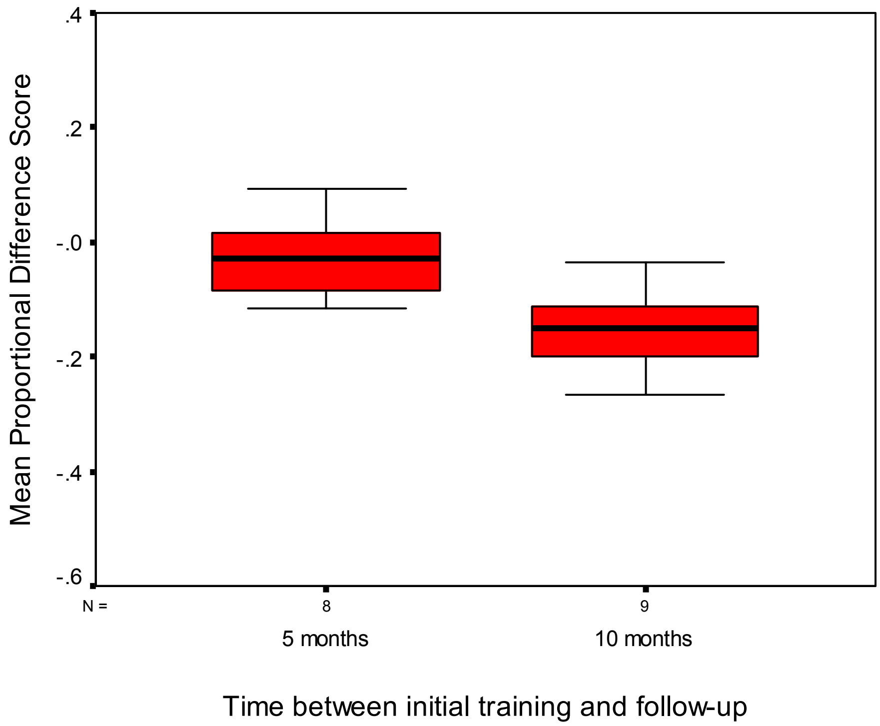


Figure 6. Mean proportional difference score data for Stimulus-specific loss (6a) and Task specific savings (6b) for the CHI participants that returned at 5 months or 10 months.

6a.



6b.

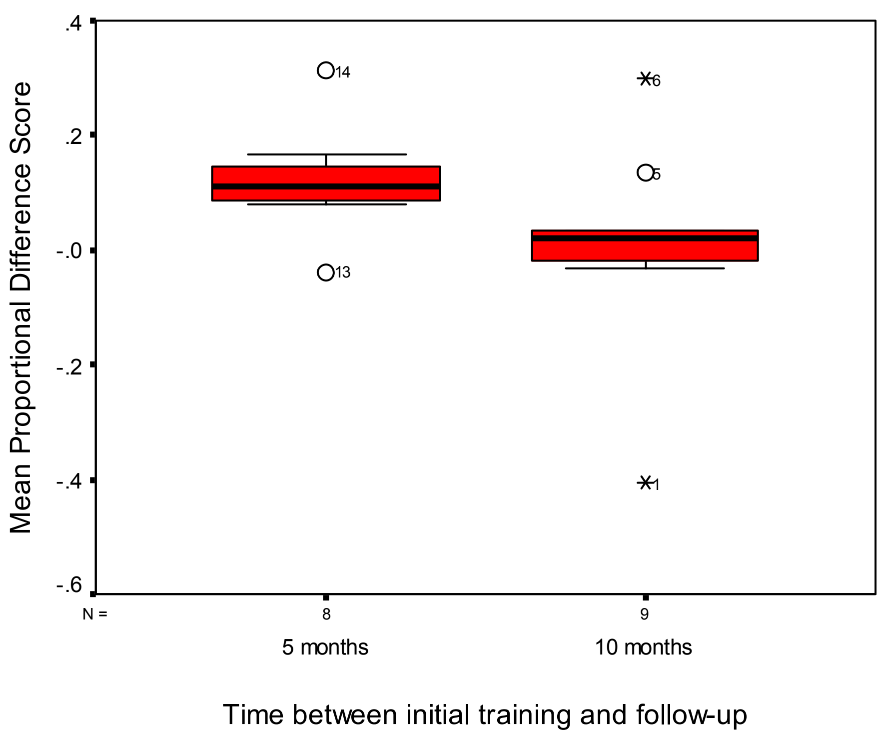


Figure 7. Mean reaction time data plotted as a function of consistent mapping (CM) practice for the CHI participants returning after 5 months and 10 months. Each CM training block represents a total of 300 trials collapsed across set sizes 2, 3, & 4.

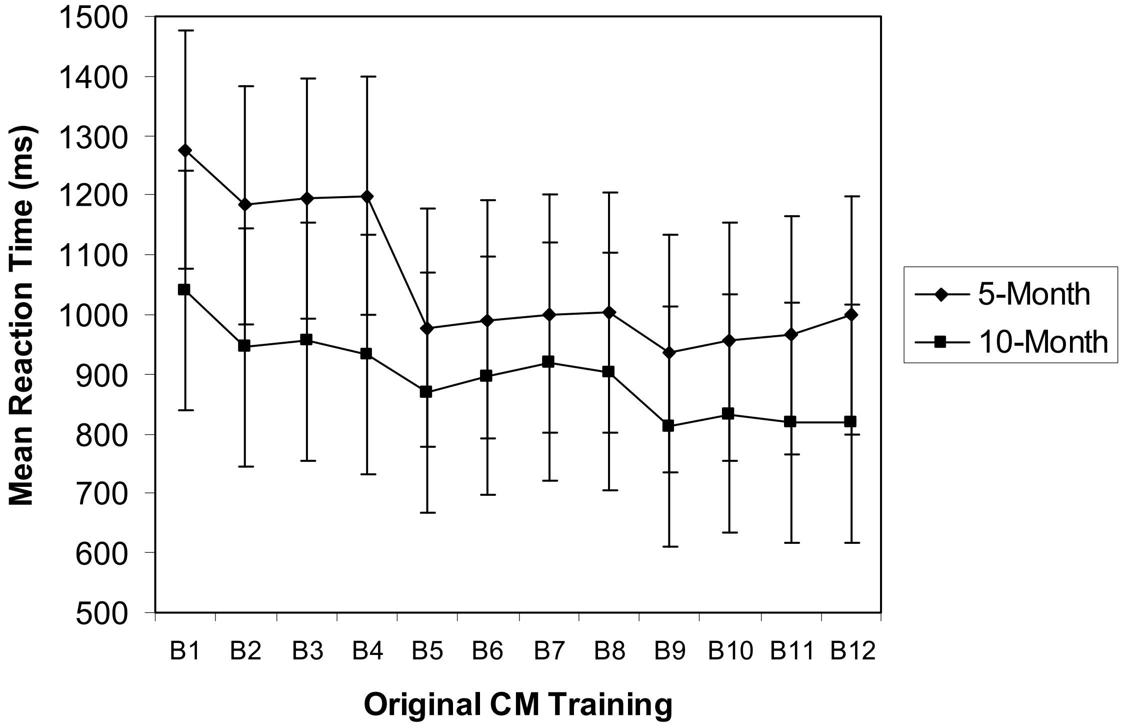
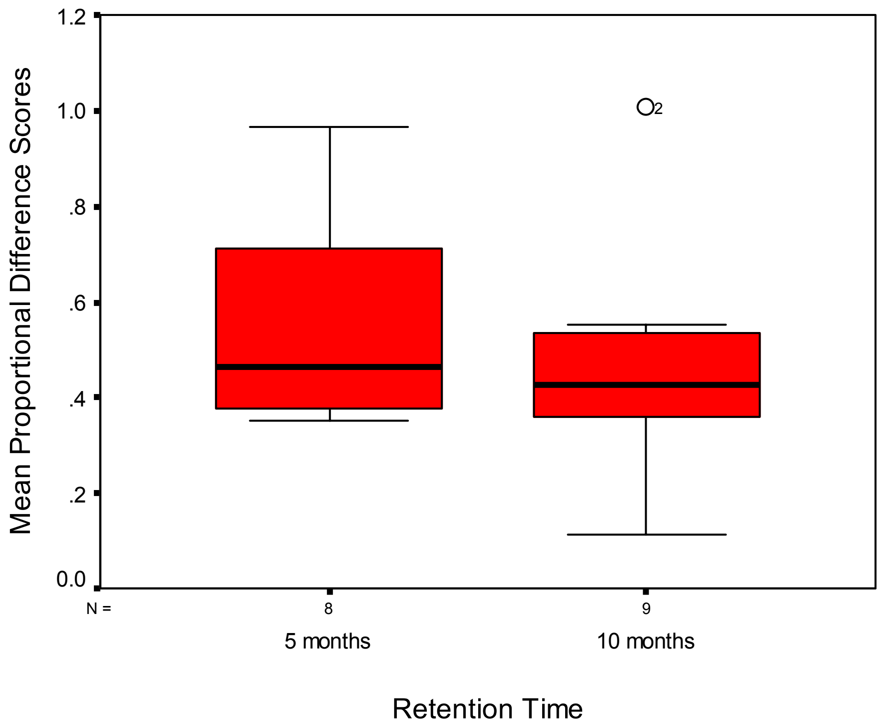


Figure 8. Mean proportional difference score data for the CM Reversal Condition (8a) and the New CM Condition (8b) for the CHI participants that returned at 5 months or 10 months.

8a.



8b.

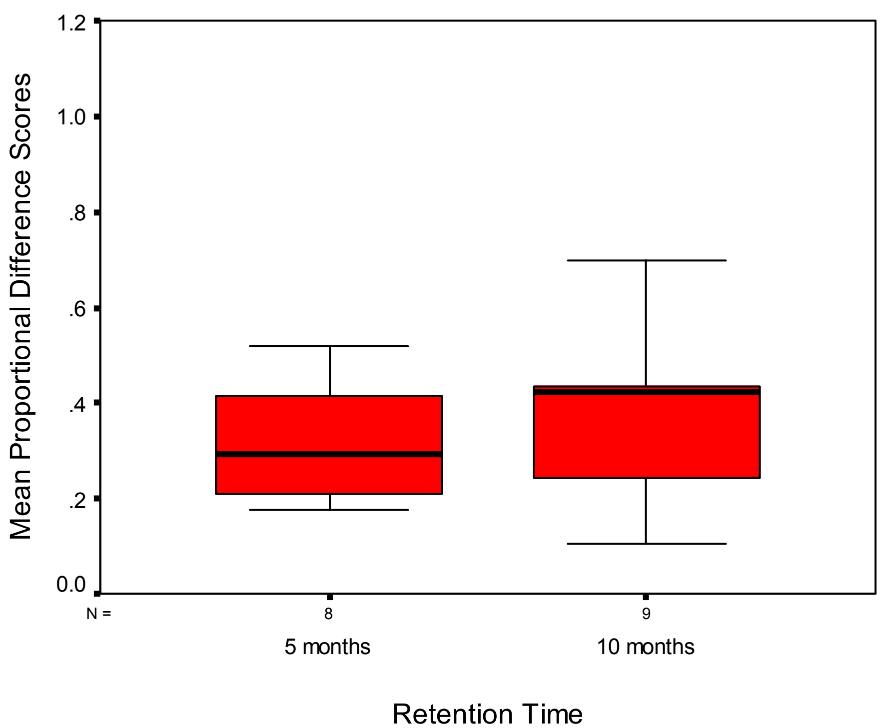


Table 3. Demographic data, injury characteristics, and neuropsychological variables for the CHI participants at the 5-month and 10-month retention interval.

	5-month			**10-month**		
Variables or test	***M***	***SD***	***N***	***M***	***SD***	***N***
Age (years)	36.80	8.79	8	31.74	9.80	9
Education (years)	13.75	1.58	8	13.89	2.26	9
Occupation status[a]						
Mother	3.57	2.30	7	2.78	1.79	9
Father	2.33	1.37	6	2.00	1.41	8
Barona FSIQ Estimate	105.38	1.88	8	104.40	5.18	9
CVLT Trials 1-5[b]	50.43	11.67	7	49.11	9.83	9
WMS-R[b]						
Visual Reproduction I	34.00	4.41	8	35.56	3.64	9
Visual Reproduction II	28.75	9.71	8	32.67	4.77	9
Logical Memory I	17.43	8.40	7	21.44	7.37	9
Logical Memory II	12.86	9.01	7	16.78	7.12	9
Category Fluency[b]	19.43	6.65	7	17.44	4.59	9
SDMT[b]						
Written	36.00	12.27	8	46.56	8.78	9
Oral	45.57	17.20	7	53.78	13.18	9
WAIS-R[b] Digit Span Subtest	14.43	1.90	7	15.67	3.91	9
Alphabet Span Test[c]	3.71	.64	7	4.06	.95	9
Time Since Injury	13.16	10.02	8	8.93	7.22	9
Coma Duration	37.88	32.38	8	22.44	20.88	9
PTA Duration[d]	106.13	111.27	8	64.11	43.16	9

Notes. CVLT = California Verbal Learning Test; WMS-R = Wechsler Memory Scale-Revised; WAIS-R = Wechsler Adult Intelligence Scale-Revised.

[a]Occupational status of each participant's parents was scored on a 6-point Occupational Scale (WAIS-R; Wechsler, 1981; 1 = *Professional and technical workers*; 6 = *Not in labor force*).

[b]Raw scores.

[c]Age-corrected score.

[d]PTA = Post-traumatic amnesia.

Figure 9. Mean reaction time data plotted as a function of the end of initial CM training and the Retention CM blocks for the CHI participants returning after 5 months and 10 months.