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ARTICLE in JOURNAL OF HEAD TRAUMA REHABILITATION · MARCH 2005

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Effects of Categorization Training in Patients With TBI During Postacute Rehabilitation
Preliminary Findings

Fofi Constantinidou, PhD; Robin D. Thomas, PhD; Victoria L. Scharp, MA; Kate M. Laske, MA; Mark D. Hammerly, PhD; Suchita Guitonde, MA

Background: Previous research suggests that traumatic brain injury (TBI) interferes with the ability to extract and use attributes to describe objects. This study explored the effects of a systematic Categorization Program (CP) in participants with TBI and noninjured controls. Participants: Ten persons with moderate to severe TBI who received comprehensive postacute rehabilitation services and 13 matched noninjured controls participated in the study. Intervention: All participants received CP training for 3 to 5 hours per week for 10 to 12 weeks that consisted of 8 levels and targeted concept formation, object categorization, and decision-making abilities. Main outcome measures: The Mayo-Portland Adaptability Inventory-3 (MPAI-3) and the Community Integration Questionnaire (CIQ). Two Categorization Tests (administered pretraining and posttraining) and 3 Probe Tasks (administered at specified intervals during training) assessed skills relating to categorization. Results: Both groups showed significant improvement in categorization performance after the CP training on the 2 Categorization Tests related to the CP. They also were able to generalize and apply categorization and sorting skills in new situations (as measured by the Probe Tasks). Participants with TBI had improved functional outcome performance measured by the MPAI-3 and the CIQ. Conclusions: The systematic and hierarchical structure of the CP is beneficial to participants with TBI during postacute rehabilitation. This study contributes to the growing body of evidence supporting cognitive rehabilitation after moderate to severe TBI.

Key words: brain injury, categorization, cognitive rehabilitation, effectiveness, efficacy, outcomes

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This research was part of a larger project supported by grants from the Center for Neuro Skills, Bakersfield, Calif; the Casa Colina Centers for Rehabilitation, Pomona, Calif; and The National Institute of Child Health and Human Development, National Institutes of Health, R15HD044554A01A1.

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problem solving. Given the fundamental importance of categorization to intelligent behavior, to observe the scarcity of investigation specific to the rehabilitation of classification behavior after TBI is surprising. This contrasts with a substantial body of work related to other domains such as attention and memory. This study proposes to fill some of this gap in knowledge and to contribute to the growing body of evidence supporting cognitive rehabilitation efforts in general.

CURRENT THEORIES OF HUMAN CATEGORIZATION ABILITIES

The literature in cognitive science investigating categorization behavior divides into 2, often noninteracting, sets: those studies concerned with how we recognize ordinary objects in the world,¹⁻³ and those whose primary purpose is to explain how categories are acquired and later used to classify novel instances.⁴⁻⁶ Only recently has there been a modest attempt to integrate these 2 areas.⁷ We summarize the main issues and theoretical ideas from each of these research domains as these ideas have motivated the development of the tasks within our proposed protocol. We then consider the very limited research concerning participants with TBI. Following that, we will present our initial evaluation of a treatment protocol, the Categorization Program (CP), whose structure was informed by the theories of categorization reviewed in this article, for its ability to improve cognitive performance.

Common object recognition

Most of the work on models of common object classification derives from cognitive neuropsychology, which seeks to develop theories of normal cognitive functioning by examining deficits in behavior due to brain injury⁸ from strokes or other focal lesions. From these clinical populations, it has been observed that brain injury often leads to dissociations in categorization ability as a function of stimulus type. For example, participants may not be able to categorize animate objects (such as animals) even though their ability to recognize artifacts remains unimpaired. There are 2 explanations of such dissociation. On the one hand, it is argued that semantic knowledge in the brain is organized into domain-specific systems. That is, systems for recognizing animals, plants, artifacts, and conspecifics occupy different anatomical regions, respectively.¹ Other accounts of the effects of brain injury adopt a property-based account of semantic memory, arguing that the observed dissociations result from the different distribution of functional versus perceptual features across different category types; animals have more perceptual properties than functional, whereas artifacts can be described using more function features.² One of the more successful models within this property-based class employs the known hierarchical processing structure of vision that begins with early feature processing and leads to the processing and representation of objects and object classes as distributed patterns over sets of properties.³

Novel category learning

When faced with learning to group novel objects or situations, people may recruit one of several systems specialized for this purpose.⁴⁻⁵ Mappings from object to category that can be described verbally, in terms of logical rules or hypotheses, utilize the left-hemisphere language centers and executive (attention and short-term memory) processes of the frontal lobes. When the categories to be learned cannot be described in terms of simple verbalizable rules (as in the case of most categories in the real world), implicit processes are needed. Models of nonverbal category learning include those that assume individuals store examples of categories with their category label in memory and base future categorization decisions on similarity to those stored examples.⁶ Similarity, in these theories, is governed by featural or property overlap that may provide the foundation for a property-based organization of semantic memory for the highly learned categories of common objects. Others
have argued that nonverbal categorization uses mechanisms similar to those of procedural learning underlying skilled motor performance and is, hence, mediated by structures involved in motor learning, namely the basal ganglia. These structures may be more resistant to the effects of brain injury, so encouraging this implicit categorization system to take over when other areas are compromised could prove useful. What is known is that explicit memory (ie, the conscious recollection of the learning event) is not necessary for category learning in some situations as individuals with anterograde amnesia (due to hippocampal damage) can learn nonverbal category structures in the absence of recalling the learning experience. Both classes of implicit models adopt the notion of similarity (or distance) between the current category representation and the object to be classified as the driving construct of category learning. Recent investigations of multiple systems of category learning suggest that initially learners attempt to use verbalizable strategies, and, if that is deemed insufficient, will gradually adopt an implicit strategy through extensive experience with the task.

**CATEGORY SYSTEMS AND REHABILITATION**

The recovery of function after brain injury has been described as analogous to the processes of development. The structure of semantic memory as used in the classification of common objects emerges as a result of the developmental process of learning novel categories in the world. Hence, there is an inherent hierarchy in the development of categorization expertise. Feature perception, similarity and difference detection, the recognition of the correspondence of properties across objects, and rule formulation are all initial processes that precede the effective use of categories for higher level cognition. The Categorization Program (CP) implemented in this project has been designed to exploit this hierarchy.

Research on the effects of TBI on categorization abilities is limited. Constantinidou and Kreimer conducted a preliminary study to determine the effects of TBI on simple object categorization and feature extraction. The results from that study suggest that moderate to severe TBI seems to interfere with the ability to extract and use attributes in order to describe objects. Participants with moderate to severe brain injury spontaneously provided significantly fewer attributes to describe common household objects compared to matched noninjured controls. However, participants with TBI were able to learn a list of 8 core attributes (color, shape, size, composition, weight, texture, detail, and function) during a multitrial (repeated presentations of the list of the 8 attributes) training session. Finally, they were able to apply these attributes to describe another set of common objects more effectively compared to their spontaneous description. While the repeated trials training session helped the performance of TBI participants, their performance was at all times significantly poorer than that of noninjured controls. These findings support the need for further exploration of the effects of TBI on categorization. In addition, the effects of a systematic rehabilitation program to improve categorization abilities of participants with moderate to severe TBI should be investigated.

Research on the effectiveness of treatment for categorization deficits is limited. In one of the few reviews of the subject, Humphreys and Riddoch survey the (very) limited number of studies examining retraining of visual object recognition of common objects following focal lesions and conclude that there is insufficient evidence of effectiveness. One reason for this lack of positive results, they indicate, is that training regimens tended to use stimulus conditions (eg, single viewpoints, fixed retinal locations, small stimulus sets, pictures only) that foster learning using cells in the early stages of the visual system that are known to be topographically organized, making generalization across situations difficult. They advocate an approach to retraining
that fosters learning to occur at higher cortical levels. By adopting a hierarchical levels-of-training approach across different categories of objects and types of materials, the training program implemented in this study embraces the recommendations of their review, in particular, for categorizing ordinary objects.

A systematic hierarchical approach has been suggested in the brain injury rehabilitation literature as a means to rehabilitate and reorganize cognitive systems and restore cognitive function. The CP is such a program consisting of 8 levels. The present project integrated principles of cognitive neuroscience and rehabilitation, designing hierarchical tasks for the two aspects of categorization described above: (1) Recognition and categorization of common everyday objects, (2) New category learning. The tasks begin with basic feature identification and feature extraction (such as color, shape, and size) and progress to higher levels of concept formation and abstraction (such as rule-based decision making). The CP provides a standardized approach to categorization training, but incorporates mastery criteria for each level in order to account for individual differences. Furthermore, the CP includes systematic cueing hierarchies and errorless learning to facilitate patient training and learning.

Efficacy research in the area of cognitive rehabilitation is greatly needed and has developed primarily in the past 10 to 15 years. Existing research and clinical protocols in cognitive rehabilitation have been criticized because of methodological and theoretical limitations such as a lack of theoretical models in the development of the clinical tasks and failure to show generalizability to functional behaviors.

The current project is part of a systematic research effort to investigate the effects of a restorative hierarchical protocol in response to the challenge set by the NIH consensus report. This protocol is innovative and based on a current theoretical model for categorization.

The purpose of the preliminary study was to obtain initial data on the effects of the systematic CP training on participants with moderate to severe TBI, enrolled in postacute rehabilitation. The hypotheses were as follows:

1. Participants with moderate to severe TBI enrolled in intensive postacute cognitive rehabilitation would demonstrate significant improvement in overall performance over their baseline scores on functional outcome measures.
2. Participants who complete the CP would demonstrate improvement in their categorization abilities as measured by the informal pretests and posttests developed as part of the CP.
3. Participants who complete the CP would demonstrate generalizability of categorization abilities to novel tasks.

METHODS

Participants

Group 1

Participants with TBI. Fourteen participants with brain injury met the study criteria for inclusion in the experimental group. One subject discontinued participation from the study because he acquired a second brain injury while participating in the project. Three others were discharged from the rehabilitation centers because of insurance complications and subsequently their participation was terminated. The remaining 10 individuals were included in the study. Their ages ranged from 19 to 50 years with a mean of 32.19 years (SD = 11.4). Education ranged from 10 to 21 years, with a mean of 13.69 (SD = 3.0). Following are the inclusion-exclusion criteria for participants with TBI.

Inclusion criteria are as follows:
1. Adult males and females between 18 and 55 years of age.
2. Primary diagnosis of moderate to severe closed head injury (CHI). The indication of an initial moderate to severe head injury was determined by the presence of three or more of the following severity indices: (a) initial Glasgow Coma
Scale score less than 12; (b) abnormal initial computed tomography (CT) findings indicating acute central nervous system pathology; (c) length of impaired consciousness greater than 20 minutes as specified by the emergency records; (d) length of posttraumatic amnesia greater than 24 hours as specified in the acute hospital/emergency records; (e) length of acute hospital stay greater than 3 days; (f) positive neurological examination on hospital admission and discharge indicating focal sensory and motor neurological deficits, or changes in the mental status attributed to brain injury; (g) medical complications secondary to the injury; (h) and head injury severity classification according to hospital records.

3. Rancho Los Amigos Scale Level VI or higher (which indicates appropriate, goal-oriented behavior, and posttraumatic amnesia (PTA) resolution).

4. No aphasia present with the exception of mild to moderate word-finding problems.

5. Resolution of PTA as evidenced by a score of 76 or higher on the Galveston Orientation and Amnesia Test.

6. Enrollment in a residential comprehensive postacute rehabilitation program at the onset of the study.

7. Participants were within 4 years of their injury.

Exclusion criteria are as follows:

1. Penetrating head injuries.
2. Diagnosis of stroke at the time of injury.
3. Premorbid central nervous system disorder or learning disability.
4. Documentation of premorbid major depression or other significant psychiatric disorder as defined by the Diagnostic and Statistical Manual of Mental Disorders, 4th ed. (commonly referred to as DSM-IV), that resulted in hospitalization, incapacity to work, or to perform activities of daily living.

5. Current Beck Depression II score of 25 or higher indicating the presence of depression that could interfere with performance on the protocol.*

6. Active or current alcohol, drug or other controlled substance abuse that interferes with participation.

7. Deficits in auditory comprehension and moderate to severe word finding problems, 2 standard deviations below the mean on the Boston Naming Test, that could interfere with the subject’s ability to follow test or task instructions.

8. English as a second language.

9. Color blindness as measured by the Ishihara test for color blindness.

The average age at injury was 31.5 (SD = 11.4) with a range of 18 to 48 years of age. The time from injury for participants before the treatment program began ranged from 1 month to 48 months with an average of 12.6 months and a median of 30 months. Fifty percent of the participants were injured in motor vehicle accidents and another 50% were injured as a result of falls. All participants received comprehensive rehabilitation at the time of participation in the project.

Group 2

Noninjured Participants. Thirteen noninjured volunteers from southwest Ohio areas who met the study’s inclusion exclusion criteria participated in the study. All were English-speaking adults aged 18 to 55 years with no history of stroke or other brain pathology. Groups 1 and 2 did not differ in age ($t(27) = 0.599, P = .554$) or years of education ($t(24) = -0.703, P = .489$).

Exclusion criteria are as follows:

1. A medical history of a central nervous system trauma, disorder, or organic brain disease.

* A higher-than-usual BDI-II cutoff (25) for subjects with TBI was set based on pilot study findings that patients with TBI (as a group) had elevated depression scores during post-acute rehabilitation; scores higher than 25 were indicative of clinical depression with this population. Beck scores can be elevated in this population because of factors specific to brain injury rather than clinical depression. Using the common cutoff of 15 with the TBI population could increase false positives.
2. Documentation of psychological or psychiatric disorder as defined by the DSM-IV:
   a. Hospitalization for major depression.
   b. Evidence of incapacity to return to work due to psychiatric disorder.
3. Current Beck Depression II score of 15 or higher, indicating the presence of depression that could interfere with performance on the protocol.
4. Mini-Mental State Examination score of 23 or lower.
5. Active or current alcohol, drug, or other controlled substance abuse.
6. Uncorrected visual deficits.
7. Uncorrected hearing impairment.
8. Language or speech disorder.
10. Color blindness as measured by the Ishihara test for color blindness.

Procedures

To enforce consistency among the clinicians who implemented the protocol, Constantinidou trained all of the clinicians involved in data collection at the collaborating research sites. Participants were administered a neuropsychological assessment, which included functional outcome measures, at the beginning of their participation in the project. Following the neuropsychological testing, participants were administered 2 informal categorization tests designed for this project (see next section for a description of the tests). Participation in the CP began immediately upon completion of all assessment. The neuropsychological assessment was repeated upon completion of the CP, which typically coincided with the time of discharge from the rehabilitation site for most TBI participants. Table 1 shows the experimental design.

Experimental items

The Categorization Program. The CP tasks were developed to target both areas of categorization: (1) Recognition and categorization of every day objects and (2) New category learning. Principles of learning, concept formation, and rehabilitation were incorporated
to develop the hierarchical tasks.\textsuperscript{10,15,16,29-31} The Appendix contains a table with the 8 levels of the CP.

**Part A of CP. Object categorization tasks**

This part consists of 5 different levels. The tasks begin with teaching perceptual features to describe objects or living things and move to higher levels of abstraction.

**Part B of CP. New category learning tasks**

The new category learning tasks consist of 3 levels, each with 5 steps that increasingly demand a higher level of rule-governed responses. Errorless learning principles and cueing hierarchies are applied under each step.

**CP Tests 1 and 2**

The 2 tests were developed to measure the effectiveness of the CP. The first test relates to the categorization of common objects (Part A of the CP). Participants were required to describe pictures of objects and identify core attributes such as their primary function and alternate uses of the object. These objects were not part of the CP. There were a total of 10 objects, 5 of which are high frequency and 5 low frequency in occurrence according to Zeno et al.\textsuperscript{32} The number correct of 120 possible was recorded for each subject.

The second test relates to the new category learning portion (Part B of the CP). Participants were required to follow a logical rule in categorizing objects. These objects were not part of the CP. There were 5 rules with increased complexity. For instance, the first rule asks the subject to “put all red items in the basket.” The last rule is more complex and requires that participants “put all things that are blue but not used for coffee in the basket.” Both informal tests were administered at the beginning and at the end of the study. The number correct of 36 possible was recorded for each subject.

**CP probe tasks**

The probe tasks were designed to assess how participants generalize information learned on the CP to other tasks not directly related to the CP training tasks. Participants are presented with an array of 10 objects and are required to categorize them on the basis of a self-generated rule. They then categorize the same objects twice, each time using a different self-generated rule.

The probe tasks were administered 3 times during the study. The first probe task was administered prior to the CP training, the second after level 2 (Part A) and the third after level 5 (Part A). Each of the probe tasks uses a set of 10 different objects, equal in familiarity and frequency of occurrence. The sequence of administration was counterbalanced to avoid order effects. Participants obtained one point for each object they sorted correctly by their self-generated rule. The subject was asked to sort the items 3 times under each probe task, each time using a different rule. Hence, each probe trial was worth 10 points with a total of 30 points for each probe task.

**CP stimuli and score sheets**

All of the items (objects, photos, written words, etc) required for the stimuli were packaged in our laboratory and provided to the sites to ensure consistency, along with the score sheets and written instructions for each level of the protocol. Cueing instructions were also included on the score sheets.

**Functional outcome measures**

Two functional outcome measures were used for this project: Mayo-Portland Adaptability Inventory-III (MPAI-3)\textsuperscript{33} and the Community Integration Questionnaire (CIQ).\textsuperscript{34} These two measures have been used widely in clinical and research work to assess functional performance, and their validity and reliability have been established in previous studies.\textsuperscript{35,36} Both instruments can be used to quantify the effects of rehabilitation after TBI. The 15-item CIQ assesses the social role limitations and community interactions of survivors of brain injury across 3 domains: home life, social
activity, and productive activities. Total scores and subscale scores for the 3 domains (home, social and productive activities) were obtained.

The 30-item MPAI-3 offers a relatively detailed measure of emotions, behavior, functional, abilities, physical disabilities, and societal participation. In addition to the total score, scores were obtained for the 2 subscales: Physical/Cognitive Impairment Scale and the Social Participation Scale.

RESULTS

Participants required an average of 12 weeks to complete the program with an average of 3 hours of treatment per week. Completion of the CP coincided with discharge from the rehabilitation facility. The functional outcome measures (CIQ and MPAI-3) were administered before and after the CP training for only the TBI group. The total score on the CIQ improved from a mean of 12.056 (SD = 6.7) to a mean of 19.11 (SD = 6.07, n = 9). The individual subscale score changes were as follows: (a) The home integration subscale score improved from a mean of 3.28 (SD = 3.04) to a mean of 5.89 (SD = 3.63); (b) The mean social integration subscale score rose from a 6.33 (SD = 2.55) to 8.44 (SD = 2.13); (c) The mean social productivity subscale score improved from 2.44 (SD = 2.35) to 4.78 (SD = 3.73).

A multivariate analysis of variance demonstrated that participants improved significantly on their CIQ performance across the 3 subscales, \( F(1, 8) = 17.08, P = .003 \), effect size = 0.681, power = 0.950. Preplanned paired samples t tests revealed significant improvement on the home integration, \( t(8) = 3.525, P = .008 \) and the productivity subscales, \( t(8) = 2.694, P = .027 \). However, there was no significant change on the social integration subscale score, \( t(8) = 2.043, P = .075 \).

Participants also demonstrated significant improvement on the MPAI-3. A decline in the score on the MPAI-3 scores indicates improvement in functional ability. The mean total score on the MPAI-3 improved from 2.31 (SD = 0.56) to 1.20 (SD = 0.63, n = 10). The individual subscale score changes were as follows: (a) The mean physical/cognition subscale score improved from 2.14 (SD = 0.59) to 1.04 (SD = 0.20); (b) The mean pain/emotion subscale score improved from 2.26 (SD = 1.13) to 1.25 (SD = 0.84); (c) The mean productivity subscale score improved from 2.54 (SD = 0.67) to 1.36 (SD = 0.86).

The multivariate analysis of variance indicated significant improvement in the posttest performance across the 3 subscales, \( F(1, 8) = 55.109, P = .001 \), effect size = 0.860, power = 1.0. Preplanned paired samples t tests showed that participants improved significantly on all of the subscale scores: (1) physical/cognition, \( t(9) = 5.950, P = .0001 \); (2) pain/emotion, \( t(9) = 3.231, P = .010 \); (3) and social participation, \( t(9) = 9.613, P = .0001 \).

All participants were given the 2 categorization tests at the beginning of their training and again upon completion of the training, approximately 12 weeks later. Table 2 displays the means for CP Test 1 by group.

To determine the effects of the CP training on categorizing familiar objects, a mixed model analysis of variance (\( \alpha = .05 \)) compared the preperformance and postperformance of the 2 groups on the CP Test 1 with 1 within (pretest/posttest performance) and 1 between (groups) factor. All participants showed improvement on the CP 1 test following the CP training, \( F(1, 20) = 88.709, P = .0001 \), effect size = 0.816, power = 1.0. Overall, normal participants scored significantly better than the TBI participants on both administrations of the CP test 1, \( F(1, 20) = 4.521, P = .046 \), effect size = 0.184, power = 0.525. The group by test interaction was not significant, \( F(1, 20) = 0.079, P = .781 \), effect size = 0.004, power = 0.058, indicating that the pattern of performance on this measure was similar for the 2 groups. Interestingly, the posttest performance of the TBI participants exceeded the baseline (pretest) performance of normal participants, suggesting improvement in categorization.

The second CP test assessed the ability to implement logical rules to categorize objects consistent with theories of category learning. Table 2 displays the means for CP Test 2 by
Table 2. Group means for CP Test 1 and CP Test 2*↑

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>Marginal means</th>
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<tbody>
<tr>
<td><strong>CP Test 1</strong></td>
<td></td>
<td></td>
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<tr>
<td>TBI Mean</td>
<td>60.33</td>
<td>97.00</td>
<td>78.667</td>
</tr>
<tr>
<td>SD</td>
<td>5.31507</td>
<td>16.963</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Noninjured Mean</td>
<td>70.0769</td>
<td>104.615</td>
<td>87.346</td>
</tr>
<tr>
<td>SD</td>
<td>9.295</td>
<td>15.861</td>
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<td>N</td>
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<td>13</td>
<td></td>
</tr>
<tr>
<td>Marginal Mean</td>
<td>6.609</td>
<td>101.50</td>
<td></td>
</tr>
<tr>
<td><strong>CP Test 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBI Mean</td>
<td>29.333</td>
<td>32.000</td>
<td>30.667</td>
</tr>
<tr>
<td>SD</td>
<td>4.153</td>
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<tr>
<td>N</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Noninjured Mean</td>
<td>30.692</td>
<td>32.615</td>
<td>31.654</td>
</tr>
<tr>
<td>SD</td>
<td>3.449</td>
<td>3.594</td>
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<td>N</td>
<td>13</td>
<td>13</td>
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<tr>
<td>Marginal Mean</td>
<td>30.136</td>
<td>32.363</td>
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</table>

*The maximum possible score on CP Test 1 is 120. The maximum possible score on CP Test 2 is 36.
↑CP indicates Categorization Program; TBI, traumatic brain injury.

group. A mixed model analysis of variance (α = .05) with 1 within (prescores/postscores) and 1 between (groups) factor compared the pretest and posttest performance of the 2 groups on the CP Test 2. Both groups scored significantly better on the posttest than on the pretest, F(1, 20) = 11.860, P = .003, effect size = 0.372, power = 0.906. Overall, normal participants performed similarly to participants with TBI on both administrations of the CP test 2 and the main effect for group was not significant, F(1, 20) = 0.538, P = .472, effect size = 0.026, power = 0.108. The group by test interaction was not significant, F(1, 20) = 0.311, P = .583, effect size = 0.015, power = 0.083, indicating that the patterns of performance on this measure were similar for the 2 groups.

The probe tasks were designed to assess the participants' ability to implement skills learned during the CP and categorize new objects. The 3 probe tasks were administered at three different intervals: before the CP training, after Level 2 and after Level 5. A mixed model analysis of variance was performed with one within (probe tasks) and one between (groups) factor. Normal participants performed significantly better overall on the three probe tasks, F(1, 19) = 16.999, P = .001, effect size = 0.468, power = 0.972. The multivariate group by probes interaction was also significant, suggesting that the patterns of performance of the 2 groups across the 3 probes were different, F(2, 18) = 7.291, P = .005, effect size = 0.448, power = 0.890. The performance of normal participants hovered around 29 points across the 3 administrations. On the other hand, participants with TBI scored much lower during the first probe, and their performance improved systematically in a linear fashion as they received more training on the CP. The performance of TBI participants eventually approximated that of normal participants. The overall multivariate probe effect was also significant, F(2, 18) = 7.408, P = .004, effect size = 0.451, power = 0.895, reflecting the improvement on the three probes demonstrated by participants with TBI. Figure 1 is the graphic plot of the interaction effect. Table 3 displays the group means on the 3 probe tasks. Figure 1 is the interaction effect.

DISCUSSION

A primary objective of this study was to determine the effects of a systematic categorization training program on categorization abilities in participants who sustained TBI and are enrolled in comprehensive cognitive rehabilitation. The study implemented a systematic CP based on current theoretical models of cognition and rehabilitation.10 Consistent with theories of human categorization, the CP incorporated passive object categorization as well as category learning and decision making tasks.

Categorization was measured by the 2 CP tests and the 3 probe tasks that were developed specifically for this project. In addition,
overall functional performance was measured with the MPAI and CIQ scales, which have been used widely to assess functional recovery following head trauma.33-36

Participants in the project showed improvement in their ability to categorize common objects as measured by their performance on CP Test 1. CP test 1 incorporates the ability to describe objects effectively and to generate creative uses that could improve functional problem-solving abilities. While the performance of participants with TBI was at all times lower than the performance of noninjured controls, the performance of the former after completion of CP training improved and exceeded the baseline (eg, pre-CP training) performance of normal participants on certain tasks.

The results are consistent with Constantinidou and Kreimer12 who reported that persons with TBI can learn how to use distinctive features (color, shape, size, etc) in describing common objects more effectively. However, the Constantinidou and Kreimer12 study tested only the effects of feature training, which served as a precursor to the CP. They did not incorporate other levels of categorization training (such as similarities and differences, functional problem solving, and abstract categorization).

Participants also demonstrated improvement in their ability to categorize on the basis of the predetermined rules as measured by improvement in performance on the CP Test 2. Both groups of participants demonstrated improvement on the test. Unlike their performance on CP Test 1, participants with TBI performed similarly to the noninjured participants on CP Test 2. The lack of group difference may be due to the nature of the

<table>
<thead>
<tr>
<th></th>
<th>Probe 1</th>
<th>Probe 2</th>
<th>Probe 3</th>
<th>Marginal means</th>
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<tbody>
<tr>
<td><strong>TBI</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20.80</td>
<td>27.70</td>
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<td>26.100</td>
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<td>SD</td>
<td>7.89</td>
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<td>.632</td>
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<tr>
<td>N</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Noninjured</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>29.545</td>
<td>29.909</td>
<td>29.727</td>
<td>29.727</td>
</tr>
<tr>
<td>SD</td>
<td>.934</td>
<td>.301</td>
<td>.647</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Marginal</td>
<td>25.38</td>
<td>28.86</td>
<td>29.764</td>
<td></td>
</tr>
</tbody>
</table>

*The total number of possible points for each probe task is 30.
Effects of Categorization Training in TBI

During this test participants were provided with the rule and asked to classify objects based on the rule. This type of task is more passive in nature because participants were not required to delineate the rule themselves. In contrast, during the actual training tasks of the CP, participants are required to delineate the rule on the basis of feedback they received from the clinician. Therefore, the CP training tasks are cognitively more demanding and more taxing than the CP Test 2. In the future, it may be worthwhile to modify CP Test 2 to require active delineation of the rules. We had adopted a passive approach in the CP Test 2 because previous research reports that tasks that are more passive in nature provide the environmental support and structure required and enhance performance in participants with TBI.37,38

The passive thinking style that is more prominent after a moderate to severe brain injury seems to be partially responsible for the difficulty of participants to transfer and generalize their new skills into new situations. In fact one challenge in brain injury rehabilitation is the realization that brain injury survivors may experience considerable difficulty in transferring new skills (such as categorization strategies) acquired during rehabilitation into new tasks, settings, or situations.19,39 This difficulty can limit the practical impact of rehabilitation. Hence, another important objective of this study was to determine whether the CP training facilitates participants' ability to generalize their categorization skills to novel tasks as measured by the probes. The current results indicated that participants with TBI were able to implement their new skills and systematically improve their categorization performance across the 3 different probe tasks. In fact, their performance approximated the performance of noninjured participants by the third probe task. Perhaps the systematic and hierarchical nature of the CP training facilitated subject performance and provided the environmental structure and support necessary to transfer learning to new categorization tasks.

CONCLUSIONS, CLINICAL IMPLICATIONS, LIMITATIONS, AND FUTURE RESEARCH

Participants in the current project demonstrated improvement in their categorization abilities. In addition, their overall performance on functional outcome measures was significantly improved. All participants with TBI were enrolled in comprehensive postacute rehabilitation when they received CP training. Only one participant with TBI became an outpatient toward the end of the CP training program and remained in the project because the CP training neared completion. The participants received an average of 12 weeks of residential rehabilitation treatment, which apparently was beneficial in improving their overall functional and social integration abilities. The results suggest that the CP training, along with comprehensive treatment, results in improved functional performance after moderate to severe TBI.

The Task Force on Promotion and Dissemination of Psychological Procedures and the World Health Organization define efficacy research as the examination of an intervention's effect under highly controlled experimental conditions, whereas effectiveness research examines the impact of interventions in those settings or conditions in which the intervention will ultimately be delivered.30,40 The current results suggest that CP training is efficacious in improving categorization performance. The CP training implemented a standardized protocol to adhere to the parameters and rigor of experimental research. At the same time, this research was conducted in clinical settings and subject to the challenges faced in those settings (such as accommodating complex clinical schedules, staff turnover, etc). Therefore, the preliminary findings presented in this study suggest that the CP was both efficacious and effective in treating categorization deficits in participants who were enrolled in postacute rehabilitation. Systematic, restorative training can be part of the cognitive rehabilitation efforts after moderate to severe TBI.
Based on the estimations of effect size and the power analyses, the treatments implemented in this study had moderate to large effects. The study had adequate power to detect these effects. However, given the small sample size, the results should be interpreted with caution until additional studies replicate the findings. In addition, there is a need to study a control group of participants who are enrolled in postacute rehabilitation but do not receive the CP training. Furthermore, the long-term effects of CP training on categorization performance and on functional outcome measures should also be investigated. Finally, examining the effects of CP training in TBI survivors who are several years postinjury would be a worthwhile effort.

One of the strengths of the current project was the careful selection of participants to create a homogeneous sample, improve internal validity, and reduce variability in performance. However, these criteria also posed restrictions on the number of participants who could qualify to participate in the project. Furthermore, while conducting the study in the environment in which the CP was intended to be administered (postacute rehabilitation) was a strength (for the study), it also created important challenges. For instance, short length of stay in the rehabilitation program (due to discontinuation of insurance funding) resulted in subject attrition. Another limitation was staff turnover at certain rehabilitation sites and difficulties associated with staffing issues in general.

Given the current financial climate and the challenges imposed by short lengths of stay in rehabilitation centers, future research may want to modify the length of the CP training. The current "dose" of the CP training appears to be effective. However, what is the optimal "dose"? Will a shorter version of the CP yield similar results? Finally, the use of CP training in older participants who sustain brain injuries may also be a fruitful line of investigation.

ACKNOWLEDGMENTS

The authors thank the professionals and patients at the following sites for their contributions to this project: Bancroft Neuro Health, Haddonfield, NJ; Center for Neuro Skills (CNS), Bakersfield, Calif; Center for Comprehensive Services (CCS), Carbondale, Ill; Casa Colina Centers for Rehabilitation, Pomona, Calif, and ReMed, Conshohocken, Pa. Special thanks to the Advisory Committee consisting of Drs Mark Ashley, ScD (CNS), Harriet Udin Aronow, PhD (Casa Colina), Felice Loverso, PhD (Casa Colina), Daniel Keating, PhD (Bancroft), Debra Brauiling McMorrow, PhD (CCS), Lynley Ebeling, PhD (CCS), and to the late David Strauss, PhD (ReMed), for their valuable input during project development, their support during the execution of the project, and for facilitating the successful implementation of the protocol at their rehabilitation sites. In addition, we appreciate the contributions of Zenobia Mehta, MA, CCC-S (CNS), and Michelle Vaughn, MA, CCC-S (CCS), for their special efforts in patient recruitment and for the refinement of the Categorization Program. The authors are grateful to the undergraduate and graduate students in the Neurocognitive Disorders Laboratory (under the supervision of Dr Constantinidou) at Miami University who contributed endless hours for the preparation of stimuli and with data collection and data management, and to Dr Phillip Best (Department of Psychology at Miami University) and Molly Polasky, MA, CCC-SLP (Drake Center, Cincinnati, Ohio), for their expert contributions toward the development of the Categorization Program.

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The 8 levels of the Categorization Program*

<table>
<thead>
<tr>
<th>Part A: Object Categorization Tasks</th>
<th>This part consists of 5 different levels. The tasks begin with teaching perceptual features to describe objects or living things and move to higher levels of abstraction.</th>
</tr>
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<tbody>
<tr>
<td>Level 1: Perceptual Feature Training and Application</td>
<td>The purpose of this section is to train perceptual feature identification thereby building a framework for cognitive structures. The retraining of basic categorization abilities will build the foundation for more abstract functions and facilitate communication during word-finding difficulties. The goal is to have the patient learn 8 perceptual features and then consistently apply all the features to describe common objects. Objects are presented via a range of stimulus types including real objects, color photos, line drawings, written words, and spoken words.</td>
</tr>
<tr>
<td>Level 2: Similarities and Differences</td>
<td>The purpose of this level is to apply the 8 perceptual features trained in Level 1 to compare objects. Identification of similarities and differences between 2 objects of the same and of different categories using the 8 perceptual features is utilized to train conceptual thinking. The process of applying the trained perceptual features is the next layer of the continuum of concrete to abstract functional abilities. Stimulus types include color photos, written words, and spoken words.</td>
</tr>
<tr>
<td>Level 3: Functional Categorization</td>
<td>The purpose of this task is to identify functional categories and maintain the delineations within that category. There are 2 specific foci in this level that require the consideration of the features of the objects trained and applied in Levels 1 and 2: the application of retrieval strategies to generate novel items that belong in a given category and the mental flexibility required to generate alternate uses for the objects in a given category. This task enhances functional problem-solving abilities and mental flexibility.</td>
</tr>
<tr>
<td>Level 4: Analogies</td>
<td>The purpose of this level is to apply both the categorization abilities trained in Levels 1 to 3 and inductive reasoning skills in order to identify and match the concepts represented in analogies. The analogies progress from concrete to abstract to train word abstraction. Stimulus materials include multiple-choice responses for each analogy that will aid in the training process of word abstraction as needed.</td>
</tr>
<tr>
<td>Level 5. Abstract Word Categorization</td>
<td>The purpose of this level is to further develop concept formation and abstract conceptual thinking. The goal is to identify similarities and differences in abstract verbal concepts. The generation of similar word pairs using synonyms that represent the relationship between the words is incorporated to enhance cognitive and linguistic flexibility.</td>
</tr>
<tr>
<td>Part B. New Category Learning Tasks</td>
<td>They consist of 3 levels and under each level there are 5 steps that increasingly demand a higher level of rule-governed responses. Errorless learning principles and cueing hierarchies are applied under each step.</td>
</tr>
<tr>
<td>Level 1: Progressive Rule Learning 1</td>
<td>The stimuli for Level 6 vary along 2 dimensions: shape and color. The 9 stimuli include squares, circles, and triangles that are red, white, and black. Each stimulus is presented individually and a formulation of the rule that classifies each stimulus into either Category A or Category B follows.</td>
</tr>
<tr>
<td>Level 2: Progressive Rule Learning 2</td>
<td>The stimuli for Level 7 of Part B are gauges that include 2 dials that must be interpreted as a single unit. This level forces generalization into a real-world situation by simulating the reading of gauges at a power plant. The determination of Operational or Not Operational for each stimulus is utilized and the cumulative interpretation of each judgment leads to the formulation of the rule that classifies the stimuli for each of the 5 conditions.</td>
</tr>
<tr>
<td>Level 3: Progressive Rule Learning 3</td>
<td>The final explicit rule task contains the same underlying structure as the earlier 2 levels; however, this time a judgment is made using stimuli constructed from dimensions of language. This further abstracts the rule formulation and forces generalization of training to a real-world situation. The stimuli in this task consist of a summary of 3 laboratory tests (Lung Capacity, Heart Fluid, Bone Marrow Count) and their orthogonal combination with 2 measurement adjectives (Low, High).</td>
</tr>
</tbody>
</table>

*Adapted from Constantinidou et al.17