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How Does the Brain Support Script Comprehension? A Study of Executive Processes and Semantic Knowledge in Dementia

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The neuropsychological substrate of scripts, routines which guide much of human behavior, is unclear. We propose a model of script comprehension characterized by the interaction of semantic knowledge for script content, and executive resources that organize this knowledge into goal directed behavior. We examined these neuropsychological components by asking participants with Alzheimer's disease (AD) and frontotemporal dementia (behavioral disorder/dysexecutive syndrome (BDD) and semantic dementia (SD) subtypes), to judge the coherence of four-phrase scripts. The BDD group detected significantly fewer sequencing errors than semantic errors; the AD and SD groups detected these errors with equal frequency. Independent semantic measures predicted both semantic and sequencing script errors, while executive measures predicted sequencing errors only. Findings support a multi-component model of script comprehension.

Keywords: scripts, semantic knowledge, executive functioning, frontotemporal dementia, Alzheimer's disease

Several decades ago, cognitive theorists coined the term "script" in reference to a large-scale routine entailing the typical action sequence, objects, role players, and locations associated with familiar events like "going fishing," "making breakfast," "going to a movie," or "visiting the doctor" (Schank & Abelson, 1977). Scripts, which provide templates for a wide range of routine individual and social activities, are considered instrumental to human interaction and goal-directed behavior (Abbott, Black, & Smith, 1985; Abelson, 1981; Galambos, 1982; Galambos & Rips, 1982; Materska, 1996). The relevance of scripts has been evidenced by the growing body of work investigating the neuropsychological and neuroanatomic substrates that support these cognitive constructs (Allain, LeGall, Etcharry-Bouyx, Aubin, & Emile, 1999; Buxbaum, Schwartz, & Carew, 1997; Cazalis, Azouvi, Sirigu, Agar, & Burnoud, 2001; Funnell, 2001; Godbout & Doyon, 1995, 2000; Grafman, 1989; Grafman et al., 1991; Lojek-Osiejuk, 1996; Sirigu et al., 1995, 1996).

The goal-directed, sequential quality of scripts led early researchers to postulate a fundamental association between prefrontal cortex (PFC) and scripts, a hypothesis which gained support by several reports of impaired performance on measures involving scripts in patients with PFC injury (Allain et al., 1999; Godbout & Doyon, 1995, 2000; Grafman et al., 1991; Sirigu et al., 1995, 1996). The fundamental sequential nature of scripts has been bolstered by functional neuroimaging studies linking scripts with prefrontal activation (Crozier et al., 1999). In contrast to the perspective that the PFC organizes or processes the sequential information constituting a script, the PFC has been argued to have a *representational* role in storing scripts (Wood & Grafman, 2003), paralleling the hypothesized storage of object knowledge in posterior cortical areas (Chao, Haxby & Martin, 1999; Martin, Ungerleider & Haxby, 2000). According to this view, scripts (also referred to as Managerial Knowledge Units or Structured Event Complexes) are the predominant type of information represented in the PFC, and are encoded and retrieved as single, indivisible units representing the most complex type of knowledge structures (Grafman, 1989; Wood & Grafman, 2003).

However, there is reason to believe that the appreciation of scripts does not depend only on the PFC. Sirigu and colleagues (1995, 1996), for example, pointed to a crucial role for posterior cortical areas in the representation of scripts based on the observation that patients with prefrontal lesions retain knowledge for the *content* of script events despite impaired ability to organize and

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prioritize these events. This dissociation suggests the additional contribution of a separate store of semantic knowledge for the objects and actions constituting a script, perhaps supported by the temporal cortex. Indeed, left temporal activation has been observed in addition to prefrontal activation in neuroimaging studies of script processing (Crozier et al., 1999). From this perspective, a two-component model of script comprehension proposes an alternative to the representational approach—that the PFC may recruit semantic knowledge about script content from the temporal cortex and organize this knowledge into meaningful, goal-directed behavior.

The current study explored the way in which at least two neuropsychological components may contribute to script comprehension. We focused specifically on the potential roles of semantic knowledge and the organization of this knowledge into a coherent script. The distribution of neuropathology in neurodegenerative conditions such as frontotemporal dementia (FTD) and Alzheimer's disease (AD) provide the opportunity to evaluate these hypothesized components of script comprehension, given the frontal and temporal disease characteristic of these conditions (Chan et al., 2001; Rosen et al., 2002; Grossman et al., 2004; Williams et al., 2005). FTD is a neurodegenerative disease characterized by a wide range of clinical presentations and several distinct histopathologic conditions (Grossman, 2002; Snowden, Neary, & Mann, 1996). One subgroup, which we refer to as the behavioral disorder/dysexecutive (BDD) subtype, shows prominent change in social conduct and personality, including impulsive and inappropriate behavior (e.g., swearing, shoplifting), lack of concern for personal appearance and hygiene, apathy, limited empathy, and disinhibition (e.g., grabbing food from another's plate, inappropriate sexual behavior). Cognitive impairments reflecting attentional deficit and executive dysfunction frequently occur in conjunction with behavioral disturbance (Boone et al., 1999; Razani, Boone, Miller, Lee, and Sherman, 2001), potentially contributing to impaired selection and organization of the constituent objects and actions in a script. This profile is associated primarily with disease in prefrontal and anterior temporal brain regions, particularly in the right hemisphere (Grossman et al., 2004; Mychack, Kramer, Boone & Miller, 2001; Rosen et al., 2002).

Semantic dementia (SD), a second presentation of FTD, is characterized primarily by a fluent form of aphasia in which knowledge for the meaning of words and objects deteriorates (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Hodges, Patterson, Oxbury, & Funnell, 1992; Hodges, Patterson, & Tyler, 1994; Lambon Ralph et al., 1998; Lambon Ralph, Graham, & Patterson, 1999; Mummery et al., 1999; Sartori & Job, 1988; Silveri & Gainotti, 1988; Snowden, 1999). Such a deficit may compromise script comprehension by interfering with knowledge for the semantic content (objects and actions) constituting a script. This profile is typically associated with degeneration of the inferior and ventral gyri of the left temporal lobe (Gorno-Tempini et al., 2004; Grossman et al., 2004; Mummery, Patterson, Price, & Hodges, 2000). Executive functioning is generally spared early in the course of this presentation in contrast to patients with BDD. However, it may be difficult to capture the integrity of executive functions and other cognitive skills with tests that are language based.

The signature symptom of AD is episodic memory loss, reflecting an inability to encode new information as a result of hippocampal deterioration (Zabar & Kawas, 2000). Semantic and executive deficits are frequently seen in these patients as well (Grady et al., 1988; Grossman et al., 1997, 2003; Keilp, Gorlyn, Alexander, Stern, & Prohovnik, 1999). While the neuropsychological profiles of AD and FTD overlap to some extent (Hodges et al., 1999; Pachana, Boone, Miller, Cummings, & Berman, 1996), these conditions appear to differ in relative emphasis of the symptom profile, particularly earlier in the disease course.

We examined script comprehension in these patients with a test created to explore the differential contributions of executive and semantic components of script processing. Subjects were presented with four phrases and asked to judge whether the script "made sense." Some of the stimuli contained an organizational error exemplified by an incorrect ordering of the phrases in the script; other stimuli contained a semantic error exemplified by the substitution of an anomalous object or action into the script. We expected FTD and AD patients to have difficulty on this task relative to healthy seniors. Moreover, although these patients overlap somewhat in their clinical profiles, we also anticipated different performance in each group on this measure. Participants with BDD were expected to display relatively greater difficulty detecting errors in the organization of scripts secondary to executive deficits, although their attention difficulty and disorder of social comportment might also impair their ability to detect a semantic error in a script. Patients with AD and SD, by comparison, were expected to have relative impairment detecting errors in the semantic content of a script, although their semantic deficit might also limit their ability to appreciate sequencing errors.

Methods

Participants

Fifty-five participants were recruited from the outpatient clinic at the Department of Neurology at the Hospital of the University of Pennsylvania, including 15 participants with AD, 13 participants with FTD–SD subtype, 12 participants with FTD–BDD subtype, and 15 age-matched healthy controls. Participants with AD were diagnosed according to the criteria of the National Institute of Neurological and Communicative Disorders–Alzheimer's disease and Related Disorders Association (McKhann et al., 1984). This included a progressive syndrome involving prominent episodic memory difficulty, associated with circumlocutory speech, a visual constructional impairment and/or executive limitations. Participants with FTD were diagnosed according to a modified version of the Lund-Manchester criteria (The Lund & Manchester Groups, 1994; McKhann et al., 2001). FTD subgroups (SD and BDD) were based on published criteria (Neary et al., 1998) that have been modified to improve reliability (Davis, Price, Moore, Campea, & Grossman, 2001; Price, Davis, Moore, Campea, & Grossman, 2001; Grossman & Ash, 2003). Initial clinical diagnosis was made by an experienced neurologist and confirmed by at least two trained reviewers on a consensus committee through independent review of the history, mental status examination, and neurological exam. Patients diagnosed with SD presented with a fluent form of progressive aphasia that includes early and profound naming difficulty that leads to impaired lexical comprehension and eventually poor object comprehension, while patients diagnosed with BDD presented with social and behavioral difficulties.

Clinical single photon emission computed tomography (SPECT) data were available for 20 participants. These nonquantitative images were interpreted informally for the anatomic distribution of disease by a clinical neuroradiologist. Reduced temporal-parietal perfusion was seen in all five AD participants with neuroimaging data. Five of seven SD participants with neuroimaging data had reduced perfusion limited to the left temporal region. The remaining two SD participants also had some frontal hypoperfusion, and one participant was also said to have some parietal hypoperfusion. Finally, five BDD participants with neuroimaging data had prefrontal and anterior temporal hypoperfusion, with one participant showing only prefrontal changes and two showing only temporal changes. We refer the reader to a quantitative study demonstrating differential patterns of cortical atrophy on structural MRI in AD, SD, and BDD that are consistent with the diagnostic procedures used herein (Grossman et al., 2004).

Only participants meeting criteria for mild to moderate dementia were included, as defined by a score of 10 or greater (Tombaugh & McIntyre, 1992) on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975). One exception was a participant with BDD who scored 9 of 30 on the MMSE. Exclusion criteria included treatment with a sedating medication, or the presence of another condition that can interfere with cognition such as primary psychiatric illness, significant head trauma, hydrocephalus, or cerebrovascular disease. All participants were part of a large, ongoing research program at the Hospital of the University of Pennsylvania and had been thoroughly screened for sensory impairment as part of a complete neurological exam performed by one of the authors (MG). Participants were directed to bring corrective lenses and hearing aids to all cognitive evaluations. Significant visual or auditory impairment would have been identified during screening measures administered prior to the experimental test described as follows. No significant differences in age, years of education, MMSE score, or duration of illness were present across dementia groups. Healthy controls were matched with dementia groups for age and education. Table 1 summarizes the demographic characteristics of the participants.

Materials and Procedures

Scripts Test

Existing studies have generally examined script knowledge by asking participants to generate events within a given script, evoking task-related resource demands that confound interpretation of results such as mental search and retrieval as well as verbalization of information. We created the current measure of script comprehension to minimize these task-related demands and to provide a more controlled means of assessing the specific organizational and semantic aspects of a script. Scripts were selected to represent a variety of familiar activities including instrumental activities of daily living (e.g., washing the dishes), hobbies (e.g., going fishing), and social events (e.g., throwing a party). Each script was represented by a title and four events. To allow simultaneous viewing of all script events and reduce demands on memory, each script was presented in 20-point font on an 8.5″ × 11″ sheet of paper with the script title and events listed in a vertical format, numbered 1 to 4. For example, "Doing the Laundry" included 1) Carry Dirty Clothes, 2) Load Washing Machine, 3) Load Dryer, and 4) Place Folded Clothes in Laundry Basket. See Appendix A for a complete listing of the scripts.

Ambiguous items were removed after a pilot study in 10 normal controls [mean (*SD*) age = 29.9 (8.6) years], leaving 22 scripts in the final test. Each script was presented in three different conditions: 1) *Correct* condition, 2) *Sequencing Error* condition, and 3) *Semantic Error* condition. This yielded 66 items that were presented in a pseudorandom order that avoided presenting two different conditions of the same script consecutively. In the *Sequencing Error* condition, the four script events were organized incorrectly by reversing the order of two adjacent events, yet all events included the appropriate objects and actions for the activity. *Sequencing Errors* were characterized in one of two ways, either as *Physically Implausible* errors ($n = 11$) or *Conceptually Implausible* ($n = 11$) errors. A *Physically Implausible* error was one in which it would be physically impossible to accomplish the script in the presented order. For example, in "Going Fishing," it would be physically impossible for "Drop Fish in Bucket" to precede "Cast the Fishing Line." In contrast, a *Conceptually Implausible* error was one in which it would be unreasonable to perform the script in the presented order. For example, in "Selling a Car," it would not be reasonable for "Wax Car" to precede "Wash Car" (although this is not physically impossible).

In the *Semantic Error* condition, script events were arranged in the correct order, yet one event was characterized by inappropriate content. Two types of *Semantic Errors* were included to represent a broad range of script content errors. Half of the semantic errors were defined as *Object Errors* ($n = 11$) in which an inappropriate object was used in an appropriately ordered script action. For example, in "Going Fishing," the *Object Error* was "Place Flower on Hook" rather than "Place Worm on Hook." That is, the action of placing something on a hook was correct, yet the object to be hooked was incorrect. The remaining half of the semantic errors were defined as *Action Errors* ($n = 11$), characterized by inappropriate use of the correct objects in an appropriately ordered script event. For example, in "Baking a Birthday Cake," an action error was "Drop candles on cake" rather than "Stick candles on cake." There was no object substitution, yet the appropriate object was used incorrectly. Script errors are provided in Appendix B.

To assist the participant in establishing the appropriate mental set for each script, we left the first event of each script intact. That is, *Semantic Errors* were not placed in the first event of the script, but were distributed equally across the second, third, or fourth events (this is true for all but one script in which it was necessary to alter the first event in order to create a feasible error). In order to minimize potential effects of error placement in comparing *Semantic and Sequencing Errors*, both types of errors were introduced into the same script event.

We matched script content words for average length and lexical frequency (Francis & Kucera, 1982) across the two sequencing error condi-

Table 1
Mean (SD) Demographic Characteristics

	AD ($n = 15$)	SD ($n = 13$)	BDD ($n = 12$)	NC ($n = 15$)
Age (years)	73.73 (9.42)	67.15 (9.55)	67.42 (11.74)	72.00 (9.13)
Education (years)	13.64 (2.34)	15.23 (2.49)	15.78 (4.21)	15.40 (2.41)
MMSE	23.60 (4.44)	24.38 (2.40)	22.58 (6.42)	29.00 (1.07)
Disease duration	72.60 (28.12)	68.31 (24.51)	72.50 (37.68)	—

Note. MMSE = Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975); Disease duration = number of months at time of testing since onset of symptoms; AD = Alzheimer's disease; SD = semantic dementia; BDD = behavioral disorder/dysexecutive syndrome; NC = normal control.

tions and did the same for the two semantic error conditions. In addition, we matched script frequency (e.g., How often do you engage in this activity?), script familiarity (e.g., How familiar are you with this activity), script flexibility (e.g., How important is it that the actions in this script are performed in the specified order?), and item "centrality" (e.g., How important is this step in accomplishing the overall goal of the script?) across these error subgroups based on ratings by 10 normal controls obtained during the pilot study. Error subgroups were matched statistically on these variables in all but one case; scripts with physically implausible errors were judged to have fewer central actions than scripts with conceptually implausible errors.

The participant was instructed as follows: "Today you will be answering questions about different activities. Each of these activities is made up of four events. The four events should give you a good sense of the activity although they cannot cover all the events needed to complete the activity. Please decide if the activity makes sense as it is presented here." In deciding whether or not the script makes sense, participants were encouraged to consider the sequence of the events as well as the content of each event. Subjects were asked to read the event aloud to ensure reading comprehension; written scripts were supplemented by oral presentation by the experimenter in the event that participants had reading difficulty.

Participants were provided with one demonstration item and two practice items. During the practice trials, incorrect answers were queried and participants were encouraged to examine the activity more closely for errors. If the participant did not identify the error, the examiner provided the correct answer. This was done to ensure comprehension of the task demands and to demonstrate level of task difficulty. Additional instructions were provided if participants forgot the aim of the task or needed clarification of the task requirements. Depending on their ability to sustain attention and energy for the testing session, participants were tested over the course of one to two visits within a month to optimize performance.

The scripts test was administered by three different examiners. All examiners read a standard set of instructions to participants and recorded each participant's responses verbatim. One examiner (SC) scored all tests. Given the straightforward and fully scripted nature of test administration and scoring, we did not feel that measures of reliability were necessary. We examined total scripts score as a function of examiner and found no significant difference, $F(2, 39) = .15$, $p = .86$.

Several clinical neuropsychological studies of executive functioning, semantic knowledge, and episodic memory were obtained as well. These studies were not selected to differentiate clinically between these patient groups as impairment may be seen on these measures for many different reasons. Rather, these measures were administered to aid in the interpretation of participants' responses on the scripts test.

Semantic Knowledge

1. Pyramids and Palm Trees Test–Words version (PPT; Howard & Patterson, 1992). The PPT is a 52-item measure of associative knowledge for objects in which participants are presented with a target written item and two written response choices. Participants are asked to decide which of the two choices (e.g., palm tree or pine tree) is the most closely related to the target item (e.g., pyramid). Impaired performance on both the visual and verbal formats of the PPT has been found in patients with SD (Bozeat et al., 2000; Hodges, Patterson, Oxbury, & Funnell, 1992; Lambon Ralph et al., 1998, 1999; Mummery et al., 1999, 2000).

2. 15-Item Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983). Subjects were asked to name 15 visual stimuli (black-and-white line drawings) presented individually. Target names were divided equally between high-frequency, mid-frequency, and low-frequency items. Subjects were given as much time as they needed to respond.

3. Verb Similarity Task (VST; Price & Grossman, 2002). The VST uses a 50-item, forced-choice, 2-alternative format based on low-to high-synonym frequency. This computerized task presents a target written verb centrally above two verbs, formatted to resemble the PPT. The participant is required to choose which of these two verbs is most similar in meaning to the target verb. Effort was made to control for a verb's semantic category (verb of motion, cognition, or perception) and argument structure (transitive vs. intransitive). All targets and forced-choice responses are matched across categories for English corpus frequency [frequency $F_{(2,141)} = 1.180$, *ns*] using Francis and Kucera (1982), and all exceed a 5:1 verb/noun ratio according to Francis and Kucera (1982) [Verb/noun ratio $F_{(2,141)} = .718$, *ns*]. In addition, all targets and responses are matched in English corpus frequency to those of the PPT [frequency $t(298) = .181$, *ns*].

Executive Functioning

1. Boston Revision of the Wechsler Memory Scale—Mental Control Subtest (WMS–MC; Lamar, Price, Davis, Kaplan, & Libon, 2002). In addition to the three tasks comprising the standard WMS-MC subtest (counting backward from 20, reciting the alphabet, and adding serial threes), the Boston Revision of the Mental Control subtest includes three nonautomatized tasks: reciting the months of the year backward, an alphabet rhyming task requiring the participant to name letters that rhyme with the word *key*, and an alphabet visualization task requiring participants to name all capital block letters that contain curved lines. The dependent variable is an accuracy index (AcI) derived from the three nonautomatized tasks using the following algorithm: AcI = $\{1 - [(\text{false positives} + \text{misses})/\text{possible correct}]\} \times 100$. This algorithm yields a percentage score ranging from 0 to 100, such that participants obtaining a score of 100% correctly identified all targets and made no false positive responses or misses.

2. Controlled Oral Word Association (COWA; Spreen & Strauss, 1998). Participants were given 60 seconds to generate words beginning with a specified letter (i.e., F, A, and S) excluding proper nouns and numbers. The dependent variable is total number of nonrepeated words in 3 minutes.

3. Trail Making Test Part B (Reitan, 1958). Participants were shown a group of printed numbers (1–13) and letters (A-L) randomly distributed on a page and asked to connect these stimuli in ascending order by alternating between numbers and letters (e.g., 1A, 2B, 3C, etc.). Errors were corrected as the participant proceeded through the test, and the discontinuation time was 5 minutes. The dependent variable was total number of seconds to completion or discontinuation.

Verbal Learning

1. Philadelphia Repeatable Verbal Learning Test (P(r)VLT; Price et al., 2002). The PrVLT is a 9-word, 5-trial, list-learning task modeled after the 9-word California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987; Libon et al., 1996) specifically designed to assess learning and memory in dementia. The discriminability index on the recognition section was chosen as the dependent variable as it has been found to correlate most highly with the volume of the hippocampus and parahippocampal gyrus, structures known to be involved in the learning of new information (Libon et al., 1998).

Results

Script Comprehension

A 4 × 2 multivariate analysis of variance (MANOVA), with a group (4 – NC, AD, SD, BDD) × error type (2 – sequencing errors, semantic errors) design, was used to examine overall group performance and to assess differences in sequencing errors versus semantic errors on the scripts test. There was a significant main effect for group, $F(1, 51) = 13.56$, $p = .001$. Post hoc analyses using a Student-Newman-Keuls procedure ($p < .05$) revealed that all dementia groups performed significantly worse than healthy seniors on the scripts test (See Table 2). Participants with BDD obtained the lowest average performance, with 75.0% of this group differing from controls by ≥2.0 SD. BDD participants also scored significantly worse than participants with AD, 60% of whom differed in performance from controls by ≥2.0 SD. Scores obtained by participants with SD were not statistically different from either the AD or BDD groups, although 84.6% of individual SD participants differed from controls by ≥2.0 SD.

The MANOVA also showed a significant interaction effect for group by error type, $F(3, 51) = 5.36$, $p = .003$. There was no statistical difference in the number of sequencing errors ($M = 1.67$, $SD = 1.89$) and semantic errors ($M = 1.67$, $SD = 1.18$) made by normal control participants. Follow-up paired-sample t tests were used to assess differences in the number of sequencing versus semantic errors within each diagnostic group (see Table 2). Cohen's d was calculated as a measure of effect size, and represents the difference in means calibrated in pooled standard deviation units (Zakzanis, 2001). Participants with BDD had significantly greater difficulty detecting sequencing errors than semantic errors, $t(11) = 3.79$, $p = .003$, $d = 2.3$. Patients with SD were equally impaired at detecting semantic errors and sequencing errors, $t(12) = .16$, $p = .88$, $d = 0.01$. Similarly, patients with AD were equally impaired at detecting semantic errors and sequencing errors, $t(14) = 1.72$, $p = .11$, $d = 0.96$. Independent-sample t tests were also used to assess between-group differences on sequencing errors and semantic errors. Participants with BDD made significantly more sequencing errors than participants with AD, $t(25) = 2.20$, $p = .04$, $d = 0.90$. All other comparisons were not significant.

A 4 × 2 MANOVA with a group (4 – NC, AD, SD, BDD) × sequencing error type (2 – physically implausible, conceptually implausible) design evaluated sequencing errors in more detail. This did not yield a significant main effect for group, $F(1, 51) = .13$, $p = .72$, but there was a significant interaction effect of Group × sequencing error type, $F(3, 51) = 3.71$, $p = .02$, $d = 0.50$. As summarized in Table 3, follow-up t tests revealed that the AD group had significantly greater difficulty identifying conceptually, rather than physically, implausible script sequencing errors. There was no difference across sequencing error types in the BDD group.

A 4 × 2 MANOVA, with a group (4 – NC, AD, SD, BDD) × semantic error type (2 – object, action) design evaluated semantic errors in more detail. This yielded a significant main effect for group, $F(1, 51) = 36.51$, $p < .001$, $d = 1.7$. However, there was no interaction effect for Group × semantic error type, $F(3, 51) = 1.50$, $p = .23$. As shown in Table 3, follow-up paired-sample t tests revealed that all groups, including normal control participants, had significantly greater difficulty detecting action-based semantic errors than object-based semantic errors.

Table 2
Mean (SD) Total Correct, and Mean (SD) Sequencing Errors and Semantic Errors on the Scripts Test

	AD (n = 15)	SD (n = 13)	BDD (n = 12)	NC (n = 15)
Scripts total correct	52.3 (10.6)	48.4 (10.2)	43.5 (12.1)	61.6 (2.7)
Sequencing errors	6.3 (6.2)	7.5 (5.5)	12.1 (7.4)	1.7 (1.9)
Semantic errors	4.7 (3.5)	7.4 (5.1)	7.1 (5.6)	1.7 (1.2)

Note. AD = Alzheimer's disease; SD = semantic dementia; BDD = behavioral disorder/dysexecutive syndrome; NC = normal control.

Script Processing and Neuropsychological Tests

Table 4 summarizes the results of the neuropsychological tests. Recognition memory discriminability is the only variable demonstrating a significant difference across the three dementia groups, $F(2, 40) = 5.64$, $p = .007$. Follow-up t tests revealed that the AD group had significantly lower recognition discriminability than the SD group, $t(26) = 3.33$, $p = .003$, $d = 1.3$, and BDD group, $t(25) = 2.45$, $p = .022$, $d = .98$.

We conducted regression analyses in the entire group of dementia subjects to evaluate the relative contributions of executive dysfunction, semantic impairment, and episodic memory deficit to semantic errors and sequencing errors in a script. z-scores were derived from performance on each neuropsychological measure relative to the performance of control subjects. z-scores from two executive measures (Trail Making Test Part B and WMS–MC Non-Automatized Index), judged to be less sensitive to semantic influence as compared to FAS (verbal fluency), were averaged to create a single executive index score. Similarly, z-scores from two semantic measures (PPT–Words and Naming), judged to have relatively small executive demands as compared to the Verb Similarity measure (Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001; Rhee, Antiquena, & Grossman, 2001), were averaged to create a single semantic index score. The recognition discriminability z-score from the verbal learning measure represented the episodic memory index.

These three neuropsychological indices were entered in a single step as independent variables in two linear regression analyses, with script sequencing errors and script semantic errors serving as two separate dependent variables. The tolerance for entry was an F-ratio of 3.84, equivalent to $p < .05$. In the regression analysis examining the factors contributing to sequencing errors, Table 5 shows that the index of executive functioning was a highly predictive independent variable. The semantic index also contributed to predicting sequencing errors, albeit to a lesser extent. The regression analysis predicting semantic errors shows that performance on the semantic index was the only significant predictor of semantic errors. The memory index did not contribute to either regression analysis.

Discussion

Originally defined by computer programmers as chains of causal inferences that connect stereotypic action sequences (Schank & Abelson, 1977), scripts are now thought by some to be meaning-based descriptions of large-scale, familiar routines (Allain et al., 1999; Buxbaum et al., 1997; Cazalis et al., 2001; Funnell, 2001; Godbout & Doyon, 1995, 2000; Grafman, 1989; Grafman et al., 1991; Lojek-Osiejuk, 1996; Sirigu et al., 1995, 1996; Wood & Grafman, 2003). As multistep plans, scripts guide many aspects of human thought and behavior, allowing for goal-directed and purposeful routines. Several studies have hypothesized that scripts are represented as unitary, indivisible knowledge structures. Other

Table 3
Mean (SD) Performance and Within-Group Differences for Script Error Subtypes

	Sequencing error type					
	Conceptually implausible	Physically implausible	*n*	*t*	*p*	*d*
NC	0.93 (1.10)	1.07 (1.10)	15	0.41	.69	0.22
AD	3.73 (3.43)	2.60 (2.97)	15	2.83	.01	1.50
SD	3.31 (3.20)	4.23 (2.74)	13	1.43	.18	0.82
BDD	5.83 (4.04)	6.25 (3.50)	12	0.89	.39	0.54
	Semantic error type					
	Object-based	Action-based	*n*	*t*	*p*	*d*
NC	.27 (.59)	1.27 (1.16)	15	2.84	.01	1.54
AD	1.13 (1.77)	3.60 (2.38)	15	4.16	.00	2.20
SD	2.62 (2.99)	4.77 (2.80)	13	2.84	.02	1.62
BDD	2.83 (2.59)	4.17 (3.41)	12	2.40	.04	1.46

Note. Total possible number of conceptually implausible errors on scripts test = 11; physically implausible errors on scripts test = 11. Total possible number of object errors on scripts test = 11; action errors on scripts test = 11. AD = Alzheimer's disease; SD = semantic dementia; BDD = behavioral disorder/dysexecutive syndrome; NC = normal control.

work, however, has suggested a two-component model consisting of semantic knowledge and organizational processes—a conceptualization which supports a flexible and adaptive system that can modify itself based on the specific contingencies of a situation.

The current study tested the latter model by evaluating whether the meaning-based and organizational components of a script can be identified in patients suffering from focal neurodegenerative diseases that interfere with executive functioning and semantic knowledge. The comprehension paradigm we developed to examine these components minimized task-related demands that might confound the interpretation of performance. We found that all dementia groups are significantly impaired at script comprehension. This was most evident in participants with BDD, who performed significantly worse than participants with AD. An analysis of error profiles revealed that difficulty in BDD participants was due largely to their significant deficit in the organizational component of a script, although these patients also were somewhat impaired in their appreciation of the semantic component of a script. Participants with SD and AD were equally impaired in the organizational and semantic components of script comprehension, perhaps reflecting a material-based deficit related to verbal administration of the test. We discuss the potential contributions of executive and semantic processes to script comprehension below.

Executive Functioning in Script Comprehension

BDD participants were the most impaired subgroup in overall script comprehension. These patients did not have an undifferentiated deficit in script comprehension, but were significantly more impaired at detecting sequencing errors than semantic errors. This group also made significantly more sequencing errors than participants with AD. The disproportionate sequencing difficulty in the BDD group is consistent with the large body of literature that links sequencing and organizational deficits to compromised prefrontal cortex (Fuster, 1980, 1997; Luria, 1966; Smith & Jonides, 1999; Stuss & Benson, 1984) and supports studies suggesting that the processing of a script's organizational structure can deteriorate out of proportion to degraded knowledge for script content. Regression analysis in the current study further supported the hypothesis that executive dysfunction makes a unique contribution to the recognition of sequencing errors within a script.

The current study extends findings from previous studies that have used generation tasks to investigate script knowledge. Such studies have required participants to produce events within a specified script, analogous to measures of category naming fluency (Godbout & Doyon, 1995, 2000; Grafman et al., 1991; Sirigu et al., 1995, 1996). This kind of production task unfortunately confounds task-related executive resource demands with the executive resources contributing to script comprehension. The fact that we found an organizational impairment on a recognition-based task in BDD participants with prefrontal disease, that is significantly worse than their semantic impairment, supports the hypothesized role of an organizational component in script processing, and emphasizes the contribution of prefrontal brain regions in processing the organizational structure of a script.

Impaired recognition of sequencing errors in this dementia group is consistent with a functional neuroimaging study conducted by Crozier and colleagues (1999) who asked a group of healthy young adults to detect ordering errors in two types of tasks. In the syntax task, participants were shown two sentence fragments (e.g., the message twice/announced was). In the script task, participants were shown two *events* within a script (e.g., get dressed/take a shower). While performance on both tasks was associated with activation in areas previously implicated in language functioning (left-sided activation of premotor cortex, posterior middle frontal gyrus, inferior frontal gyrus, temporal sulcus, and supramarginal gyrus), the script task yielded more extensive activation including left- and right-sided prefrontal activation (middle frontal gyrus, supplementary motor area, and inferior frontal gyrus) and

Table 4
Mean (SD) Raw and Standardized Performance on Neuropsychological Measures

	BDD	SD	AD	NC
	Semantic			
Raw scores				
PPT–Words (maximum = 52)	47.3 (3.9)	44.6 (4.9)	46.6 (5.9)	50.9 (1.3)
Verb Similarity Test (maximum = 50)	37.4 (5.5)	39.2 (8.5)	40.5 (7.1)	47.4 (1.7)
Naming (maximum = 15)	11.6 (4.1)	10.0 (3.3)	11.3 (3.5)	N/A
	Executive			
Trails B Time (seconds)	241 (79.0)	240 (81.0)	252 (67.0)	98.1 (19.5)
WMS–MC (maximum = 100%)	52.3 (31.4)	47.0 (30.8)	66.7 (26.7)	92.3 (7.7)
COWA	20.2 (10.5)	20.6 (13.0)	25.6 (16.8)	45.3 (15.3)
	Memory			
Recognition discriminability (maximum = 100%)	66.0 (17.0)	69.0 (14.0)	51.0 (15.0)	96.3 (5.0)
	Semantic			
z-Scores				
PPT–Words	−2.8 (3.1)	−5.0 (3.8)	−3.4 (4.7)	
Verb Similarity Test	−5.8 (3.2)	−4.8 (4.9)	−4.0 (4.1)	
Naming	0.2 (1.1)	−0.3 (0.9)	0.1 (0.9)	
	Executive			
Trails B Time	−7.3 (4.0)	−7.3 (4.1)	−7.9 (3.4)	
WMS–MC	−5.1 (4.1)	−5.9 (4.0)	−3.5 (3.5)	
COWA	−1.6 (0.7)	−1.7 (0.9)	−1.3 (1.1)	
	Memory			
Recognition discriminability	−6.1 (3.5)	−5.5 (2.8)	−9.1 (2.9)	

Note. AD = Alzheimer's disease. SD = semantic dementia. BDD = behavioral disorder/dysexecutive syndrome. NC = normal control. N/A = not administered. PPT–Words = Pyramid and Palm Trees Test (Word Version); COWA = Controlled Oral Word Association Test; WMS–MC = Boston Revision of the Wechsler Memory Scales—Mental Control Subtest (Non-Automatized Index); Recognition discriminability = Discriminability Index from the recognition portion of the Philadelphia Repeatable Verbal Learning Test. *z*-scores were derived in relation to the mean performance of age and education matched healthy controls, except for Naming which was based on the overall mean performance across the three dementia groups as control subjects did not receive this test.

left parietal activation (angular gyrus). Crozier and colleagues speculated that the role of bilateral prefrontal activation in the script condition might be specific to event sequencing.

Because of the typical distribution of disease in BDD, the current findings are consistent with the idea that the PFC contributes to the organization of events within a script. This contrasts with the *representational* account of the prefrontal cortex (Wood & Grafman, 2003) in which all aspects of a script—including script content and the way in which this content is organized—should be compromised following prefrontal disease. The selectively greater impairment for organizational aspects compared to semantic knowledge of a script in BDD participants is more consistent with a two-component model that dissociates script organizational processes from the semantic knowledge in scripts.

Semantic Knowledge in Script Comprehension

If a script is stored as a unitary knowledge structure, independent of the semantic representations of the objects and actions contributing to the script, impaired semantic knowledge should not affect script comprehension. In contrast, a multicomponent model of script processing would leave script comprehension susceptible to degraded semantic knowledge of the objects and actions that contribute to a script. In fact, a regression analysis showed that across all groups, semantic errors on the scripts test were predicted only by performance on a separate index of semantic knowledge; executive and memory abilities were unrelated to semantic script errors.

Participants with the greatest deficit in semantic knowledge, the SD group, evidenced significant difficulty detecting both semantic and sequencing errors on the scripts test compared to healthy controls. This is not entirely surprising, given that the verbal format of the test put these participants at a disadvantage for recognizing both semantic and sequencing errors. Indeed, regression analysis suggested that poor recognition of sequencing errors was influenced in part by impairment on the measure of semantic knowledge. This resembles the disadvantage that SD patients have on standard measures of executive functioning such as letter fluency which have a lexical semantic component. In order to address

Table 5
Regression Analyses Relating Neuropsychological Indices to Script Errors

Dependent variable	Adjusted R^2	F	Predictor	Beta	p
Sequencing errors	.35	7.73	Executive Index	−.38	.02
			Semantic Index	−.31	.05
			Memory Index	−.12	.25
Semantic errors	.22	4.49	Executive Index	−.30	.30
			Semantic Index	−.39	.02
			Memory Index	−.11	.44

Note. Executive Index = Average *z*-score for Trail Making Test Part B and the Mental Control Subtest (Non-Automatized Index); Semantic Index = Average *z*-score for Pyramid & Palm Trees Test (Word Version) and the 15 item Boston Naming Test; Memory Index = *z*-score for the discriminability index from the recognition portion of the Philadelphia Repeatable Verbal Learning Test.

this confound, data with a visual format of the test are being collected.

Conclusions

Results from the current study suggest that executive and semantic processes independently contribute to performance on a test of script comprehension. The idea that scripts are not stored as unitary, rigid knowledge structures is consistent with the sense that a script is rarely executed in exactly the same fashion, and instead varies depending on a variety of factors such as personal goals and environmental constraints. However, several limitations to the current study should be kept in mind when considering our findings. One limitation mentioned above concerns the verbal administration of the scripts test that may have resulted in a material-based deficit detecting both semantic and sequencing error in patients with a primary language deficit. Another limitation is the overlapping performance profiles on the independent neuropsychological measures of semantic and executive functioning seen across patient groups. At first glance, this may suggest that patients have comparable impairment levels in a given domain; however, there are many reasons why a patient may be impaired on a given task. For example, PPT performance may be impaired in SD because of a semantic memory deficit, but this task may be difficult for BDD patients because of limited selective attention. Similarly, FAS may be impaired in BDD patients because of a poor mental search strategy, but this task may be difficult for SD patients because of limited lexical retrieval. We emphasize that the regression analyses were intended to evaluate the contribution of executive functioning, semantic knowledge, and episodic memory relative to one other, in regard to the detection of sequencing and semantic errors on the scripts test. With these caveats in mind, the results of the present study are most consistent with a multicomponent view of script comprehension where executive and semantic components both play an important role.

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Appendix A

Scripts Test Items

1. Going Camping
1. Pack food and supplies 2. Look at compass 3. Hike to campsite 4. Sleep in tent
2. Going on Vacation
1. Visit travel agent 2. Pack suitcase 3. Sit in plane 4. Look through binoculars at scenery
3. Barbecuing a Cheeseburger
1. Pour charcoal 2. Light charcoal 3. Flip hamburger with spatula 4. Place cheese on hamburger
4. Going to a Play
1. Check calendar for show time 2. Give ticket to attendant 3. Watch performance 4. Hand flower to performer
5. Going out to Eat
1. Call restaurant for reservations 2. Check in with hostess 3. Lift glass to toast 4. Eat ice cream
6. Baking a Birthday Cake
1. Remove ingredients from cabinet 2. Mix ingredients 3. Place pan in oven 4. Stick candles on cake
7. Selling a Car
1. Wash car with sponge 2. Wax car 3. Place price tag in window 4. Collect money
8. Going Fishing
1. Walk to pond with fishing rod 2. Place worm on hook 3. Cast fishing line 4. Drop fish in bucket
9. Washing the Dishes
1. Clear dishes from table 2. Scrape food from dishes 3. Wash dishes with sponge 4. Dry dishes
10. Throwing a Party
1. Write invitations for event 2. Drop invitations in mailbox 3. Get dressed for party 4. Entertain guests
11. Wrapping a Gift
1. Place gift in box 2. Cut wrapping paper 3. Wrap box 4. Place bow on top of box

Appendix A—(Continued)

Scripts Test Items

12. Graduating from School
1. Study class material 2. Receive diploma 3. Throw graduation cap in air 4. Start new job
13. Making a Necklace
1. Lay out beads and ball of string 2. Unravel string 3. String beads together 4. Place clasp on necklace
14. Sending a Letter
1. Write message 2. Put letter in envelope 3. Seal envelope 4. Place stampt on right corner of envelope
15. Going to the Movies
1. Check newspaper for movie schedule 2. Approach movie theater 3. Hand ticket to attendant 4. Watch movie
16. Doing the Laundry
1. Carry dirty clothes 2. Load washing machine 3. Load dryer 4. Place folded clothes in laundry basket
17. Grocery Shopping
1. Check grocery list 2. Push cart into store 3. Take milk off shelf 4. Pay cashier
18. Making a Sandwich
1. Lay out bread 2. Spread mustard on bread 3. Lay meat on bread 4. Cut through sandwich with knife
19. Going Skiing
1. Drive with skis on car 2. Ride chair lift 3. Stand on skis to go down mountain 4. Drink hot chocolate
20. Painting a Picture
1. Pour paint onto palette 2. Place brush in paint 3. Stroke canvas with brush 4. Hang painting
21. Going to Work
1. Wake with alarm clock 2. Look in closet for clothes 3. Iron shirt 4. Sit at work
22. Driving a Car
1. Secure seatbelt 2. Place key in ignition 3. Check rearview mirror 4. Drive car

(*Appendixes continue*)

Appendix B

Semantic Errors

Script	Action-Based Errors
Going Camping	Sleep on top of tent
Going on Vacation	Look through binoculars at map
Going out to Eat	Toss glass to toast
Baking a Birthday Cake	Drop candles on cake
Graduating from School	Step on graduation cap
Making a Necklace	Tie string around jar of beads
Sending a Letter	Place stamp on left corner of envelope
Going to the Movies	Throw ticket to attendant
Making a Sandwich	Place knife in between slices of bread
Going Skiing	Sit on skis to go down mountain
Painting a Picture	Stroke canvas with handle of brush
	Object-Based Errors
Barbecuing a Cheeseburger	Use scissors to place cheese on hamburger
Going to a Play	Hand carrot to performer
Selling a Car	Wax car with rake
Going Fishing	Place flower on hook
Washing the Dishes	Wash dishes with mop
Throwing a Party	Drop invitations in garbage can
Wrapping a Gift	Place candle on top of box
Doing the Laundry	Load stove
Grocery Shopping	Push wheelbarrow into store
Going to Work	Iron shirt with kettle
Driving a Car	Place screwdriver in ignition

Appendix C

Sequencing Errors

Script	Physically Implausible Error
Baking a Birthday Cake	Stick candles on cake BEFORE Mix ingredients
Making a Necklace	String beads together BEFORE Unravel string
Sending a Letter	Seal envelope BEFORE Put letter in envelope
Going to the Movies	Watch movie BEFORE Approach theater
Going Skiing	Stand on skis to go down mountain BEFORE Ride chair lift
Painting a Picture	Place brush in paint BEFORE Pour paint on palette
Going Fishing	Drop fish in bucket BEFORE Place worm on hook
Driving a Car	Drive car BEFORE Place key in ignition
Grocery Shopping	Take milk off shelf BEFORE Push cart into store
Throwing a Party	Drop invitations in mailbox BEFORE Write invitations
Wrapping a Gift	Wrap box BEFORE Cut wrapping paper
	Conceptually Implausible Errors
Going out to Eat	Lift glass to toast BEFORE Check in with hostess
Making a Sandwich	Cut through sandwich with knife BEFORE Lay meat on bread
Graduating from School	Start new job BEFORE Throw graduation cap in air
Going on Vacation	Pack suitcase BEFORE Visit travel agent
Barbecuing a Cheeseburger	Place cheese on hamburger BEFORE Flip with spatula
Going to a Play	Hand flower to performer BEFORE Watch performance
Selling a Car	Wax car BEFORE Wash car with sponge
Washing the Dishes	Wash dishes with sponge BEFORE Scrape food from dishes
Doing the Laundry	Place folded clothes in laundry basket BEFORE Load dryer
Going to Work	Sit at work BEFORE Iron shirt
Going Camping	Look at compass BEFORE Pack food and supplies

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