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Design Fluency Among Normals and Patients With Closed Head Injury

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A Design Fluency task was administered to 86 patients who had suffered closed head injury (CHI) with loss of consciousness and 87 normal control subjects. Subjects were asked to draw as many novel designs as they could in 5 minutes without scribbling, drawing a nameable object, or repeating a design that had been drawn previously. The mean performance of the CHI group was significantly poorer than that of the control group, with 47% of head injured performing defectively (below the 5th percentile of controls). There was no significant relationship between Design Fluency and prorated IQ, psychomotor speed, or Word Fluency. The findings demonstrate that a standardized version of the "free condition" of Design Fluency is likely to be useful in the evaluation of patients with closed head injury.

Although tests of Controlled Oral Word Association (i.e., Word Fluency) have become well established tools in neuropsychological assessment (cf. Benton, 1968; Benton & Hamsher, 1989; Lezak, 1995), its nonverbal counterpart, Design Fluency, has been less frequently used in clinical practice, particularly in the "free condition," where patient response alternatives are most unstructured (cf., Jones-Gotman & Milner, 1977). A number of design fluency tasks, both structured and unstructured, have been devised and investigated in a variety of clinical populations (cf. Lezak, 1995, pp. 668–671). In general, these studies have produced results that indicate that performance on design fluency tasks is likely to be impaired among patients with known or suspected frontal lobe damage (Bigler, 1995; Bigler et al., 1988; Daigneault, Braun, Gilbert, & Proulx, 1988; Diagneault, Braun, & Whitaker, 1992; Jones-Gottman, 1991; Jones-Gotman & Milner, 1977; Mittenberg, Seidenberg, O'Leary, & Digiulio, 1989; Ruff, 1988; Ruff, Allen, Farrow, Niemann, & Wylie, 1994; Ruff, Light, & Evans, 1987). At the same time, however, questions have been raised as to whether it is even possible to obtain a meaningful standardization sample for Design Fluency in the so called "free condition" (McCarthy & Warrington, 1990; Ruff et al., 1994), the presentation most similar to Word Fluency. There have also been very few studies concerning the clinical utility of "free condition" Design Fluency among the head injured, particularly those with mild head injury and/or those with pending litigation.

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This investigation employed a Design Fluency task in which the subject is required to draw as many original designs as possible during 5 minutes without producing a design that could be named, scribbling, or repeating a design that has been drawn previously during the exercise (i.e., the "free condition"). The study's objectives were twofold. The first was to determine whether or not meaningful normative standards could be obtained for the task (i.e., a normal distribution without a "floor effect"). The second was to establish whether or not the task had clinical utility among patients with closed head injury. In the process, it was also possible to investigate some of the neuropsychological correlates of defective performance, the nature of errors made by subjects who were impaired in Design Fluency and the relevance of pending litigation to Design Fluency performance.

METHOD

Subjects

Two groups of subjects participated in this study: (1) a group of neurologically and psychiatrically normal control subjects, and (2) a group of patients who suffered a closed head injury with loss of consciousness (CHI group).

The control group consisted of 87 volunteers, 28 males and 59 females, who denied history of neurologic or psychiatric illness, loss of consciousness (LOC) due to head trauma, and severe febrile illness.

The closed head injury group consisted of 86 patients, 45 males and 41 females, were members of this group. All were seen on clinical referral because they, their physician, and/or their family had noted significant neuropsychological or behavioral change since they suffered their head injury. LOC ranging from "a few seconds" to a maximum of 39 days of coma. However, the sample was largely composed of patients who sustained so-called "minor" or mild CHI with 70 (81%) reporting their duration of LOC as 10 minutes or less. The mean prorated WAIS IQ for CHI subjects was 106.3 (SD = 12.8; range: 59–138). The mean interval between date of injury and time of testing was 23.8 months (SD = 28.8; range: 1–214 months).

For later analyses, the CHI group was divided into two subgroups reflecting whether they were involved in litigation concerning their head injuries. The forensic subgroup consisted of 52 patients, 26 males and 26 females, who were referred for a forensic evaluation by an attorney or by a physician who had originally received a referral directly from an attorney. These patients were involved in some type of civil litigation or had litigation pending. The clinical subgroup consisted of 34 patients, 19 males and 15 females, who were referred solely for clinical evaluation.

A summary of the demographic characteristics of each subject group and subgroup is shown in Table 1. The Control group did not differ significantly from the CHI group with regard to age, gender, IQ, or education. No significant differences were found in comparison of Controls with the Clinical subgroup or the Forensic subgroup. Clinical and Forensic subgroups did not differ significantly on any of the measures shown.

Procedure

Each subject who participated in the study was tested individually and completed the "free condition" of the Design Fluency task of Jones-Gotman and Milner (1977). Subjects in the CHI Group represent a cross-section of sequential referrals of head-injury patients referred to two of the study's authors and performed the Design Fluency task as part of an

TABLE 1
Characteristics of Controls and CHI Subjects

		Control	Total CHI	Forensic	Clinical
Age					
(in years)	Mean	27.7	32.4	33.1	31.4
	SD	13.1	11.2	12.7	8.2
	Range	18–77	15–70	15–70	19–56
Education					
(in years)	Mean	14.4	13.2	13.1	13.4
	SD	2	2	2.2	1.8
	Range	12–21	9–19	9–19	12–18
LOC/PTA					
(in minutes)	Mean		4.3	4.2	4.5
	SD		9.6	9.1	10.2
	Range		0–45	0–45	0–39
Duration Since Injury					
(in months)	Mean		23.8	27.6	18.2
	SD		28.8	30.9	25
	Range		1–214	3–214	1–142
WAIS IQ					
	Mean		106.3	106.2	106.5
	SD		12.8	14.5	9.8
	Range		59–138	59–138	93–135
Novel Design					
Totals	Mean	16.1	9.2	10	8.1
	SD	9.13	8.8	5.9	5.6
	Range	4–51	0–25	0–25	1–21

otherwise routine clinical neuropsychological evaluation. The task was generally administered to volunteer control subjects as part of an hour-long experimental battery. Experimenters provided subjects with the instructions, a pencil, and paper, and indicated to them when to begin and terminate the task. For both controls and the head injured, experimenters took care to ensure that all subjects understood clearly and could repeat correctly the task instructions.

The performances of subjects and controls were scored with regard to number of Novel Designs produced. The Novel Designs score was defined as the total number of designs generated minus the number of nameable drawings, scribbles, and repetitions. Data analyses focused upon the number of novel designs produced during the 5-minute drawing period. The judgments of two trained, independent raters (not involved in the clinical assessment of patients) agreed 90% of the time with respect to the novel designs index among patients and controls. In the few instances where clear disagreements between raters could not be resolved, the conservative strategy of selecting the higher score (i.e., giving the patient the benefit of the doubt) was adopted. The 0.05 level of significance was adopted for all formal statistical tests.

RESULTS

Standardization

Novel designs were the scoring measure of greatest interest because it involved production of designs that corresponded with test instructions. An example of normal and impaired performances in this regard is shown in Figure 1.

For the Control group, the mean number of novel designs was 16.1 (*SD* = 9.1; range: 4–51). As can be seen from Table 2, the performances of controls varied widely and were

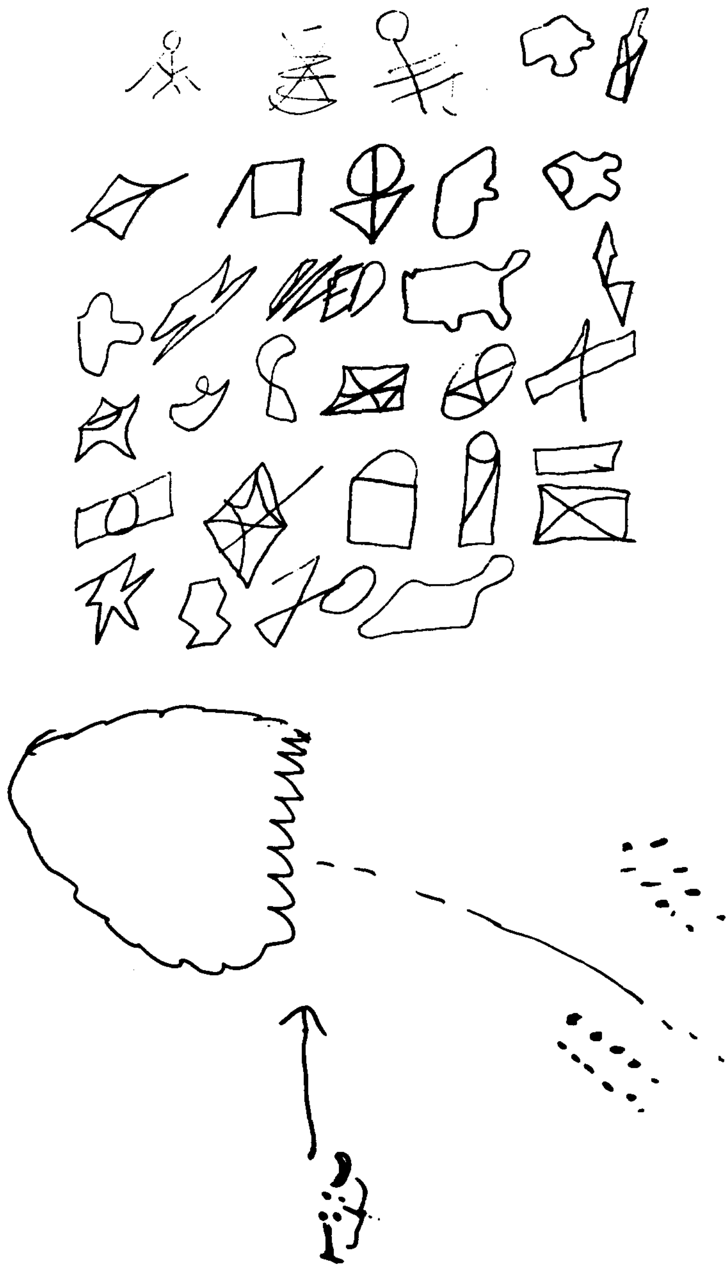

FIGURE 1. Examples of normal and impaired performance in design fluency.

normally distributed. Normal performance did not involve a "floor effect" in which scores distributed to zero correct in a significant percentage of cases. The fifth percentile was employed as the cutoff for labeling performance as defective. This fell at a raw score of seven novel designs.

Within the Control group there were no significant correlations between number of novel designs and age ($R = -.26$) or educational level ($R = -.21$). Furthermore, there was no significant difference between males (Mean = 16.2) and females with regard to number of novel designs produced (Mean = 15.7), $t = .25$, two tailed, ns.

TABLE 2
Distributions of Novel Design Scores for Controls and Closed Head Injury Subjects

Novel Designs	Control	Total CHI	Clinical	Forensic
50–51	1	0	0	0
48–49	1	0	0	0
46–47	0	0	0	0
44–45	0	0	0	0
42–43	0	0	0	0
40–41	0	0	0	0
38–39	0	0	0	0
36–37	1	0	0	0
34–35	3	0	0	0
32–33	2	0	0	0
30–31	1	0	0	0
28–29	0	0	0	0
26–27	3	0	0	0
24–25	2	2	0	2
22–23	4	0	0	0
20–21	4	4	2	2
18–19	5	3	1	2
16–17	3	8	2	6
14–15	13	3	2	1
12–13	13	7	1	6
10–11	13	7	2	5
8–9	12	12	4	8
6–7	3	14	7	7
4–5	3	11	5	6
2–3	0	12	7	5
0–1	0	3	1	2

Performances of the Head Injured

The mean number of novel designs for the CHI group was 9.24 (SD = 8.8; range: 0–25). This is significantly poorer than the mean performance of controls ($t = 5.9, p < .0001$). As can be seen from Table 2, 47% (40 out of 86) of the CHI patients performed defectively in Design Fluency (i.e., produced seven or fewer novel designs). Within this group, no significant relationships between age, education level, and task performance emerged. No indication of a significant gender effect was apparent. Within the CHI sample, no significant relationship was found between the length of the interval between time of injury and time of assessment and novel designs performance (R = .07). Task failure was more frequent among the 16 of subjects with LOC of greater than 10 minutes (n = 10; 63%), but the correlation between LOC and novel design score was only .09 (ns). The small size of this correlation doubtless reflects, in large part, an "anchor effect" from the vast majority of CHI patients with less than 10 minute LOC.

Nameable Designs

Among controls, 95% of subjects made one or fewer nameable designs. Performances involving two or more nameable designs were, therefore, viewed as being abnormal. Among head injured patients, 16% of all responses involved nameable designs, and 11% of the CHI group produced more than one nameable design. In six cases, more than four nameable designs were produced, and these represented the majority of responses. Scoring of nameable designs separately from frequency of novel designs identified 6% additional impaired performances as compared to scoring of novel designs alone. An example of performance impaired as a result of frequent nameable designs is shown in Figure 2.

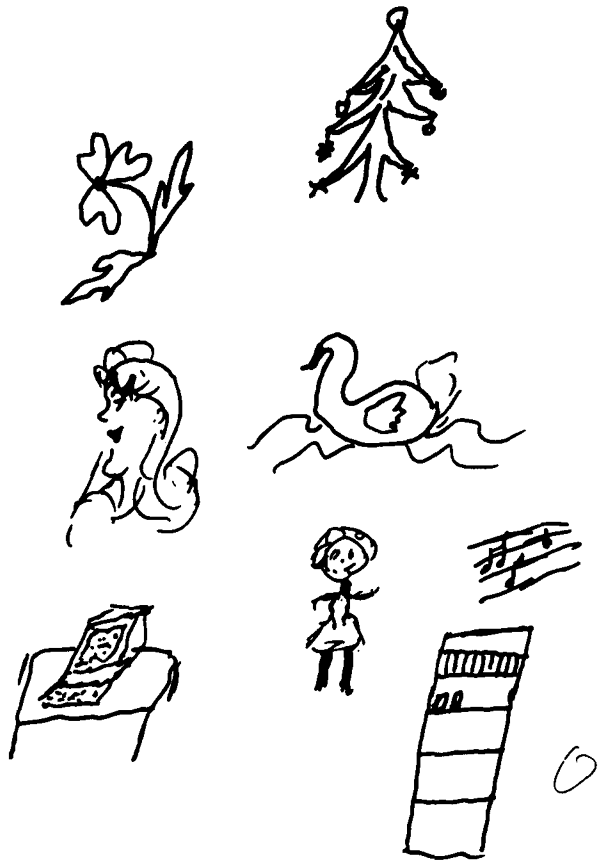

FIGURE 2. An example of design fluency with frequent nameable responses.

Perseverative Designs

Among controls, 95% made three or fewer repeated designs. Thus, a performance involving four or more repeated designs was regard as abnormal. Only 3% of patients in the CHI group made an unacceptable number of perseverative designs.

Scribbled Designs

If members of the study merely scribbled instead of producing an actual design, this was considered an error. Scribbling errors were committed very rarely by both controls or CHI patients. Thus, calculation of a cutoff point and error percentages was unnecessary.

Relationships With Other Measures

In the CHI sample (n = 86), novel designs performance correlated most highly with Controlled Oral Word Association (COWA) performance ($R = .34$; $p < .05$), using age, education, and gender corrections recommended by Benton and Hamsher (1989). However, whereas 47% (40 out of 86) of the combined CHI sample performed defectively on Design Fluency, only 13% (11 out of 86) of the participants performed defectively on COWA.

With regard to general intellectual functioning, novel designs performance correlated only 0.14 (ns) with a WAIS IQ. Correlations between novel designs performance and individual WAIS subtests ranged from –0.09 on Information to .22 ($p > .05$) on Digit Symbol. The latter was the only significant correlation involving a WAIS subtest and Design Fluency. The mean IQ of CHI subjects who failed at Design Fluency (mean IQ = 106.3) did not differ significantly from that of CHI subjects who obtained normal scores (mean IQ = 105.9). Thus, failure at Design Fluency clearly was not a reflection of general mental impairment. Similarly, the very low correlation between Digit Symbol and Design Fluency indicates that task failure was only peripherally related to problems with graphomotor speed.

Clinical Versus Forensic Subgroups

The mean number of novel designs for the forensic subgroup was 10.0 ($SD = 5.9$; range: 0–25). Forty-six percent (24 out of 52) of the sample performed defectively. Within this group, there were no significant relationships between age, educational level, or gender status and task performance.

The mean number of novel designs for the clinical subgroup was 8.1 ($SD = 5.6$; range: 1–21), which is not significantly different from the performance of the forensic subgroup. Sixty-two percent (21 out of 34) of the sample performed defectively. Chi-square analysis indicated that this was not a significantly higher proportion of failing scores than was observed in the forensic group ($p < 0.3$). Within the clinical subgroup there were no significant relationships between age or educational status and task performance, nor was there any indication of a significant gender effect.

ANOVA and Scheffe Follow-Up Tests

The results of a one-factor, between-groups ANOVA on the novel designs performance measure and subsequent Scheffe follow-up tests confirmed that the mean performances of the two CHI subgroups (Clinical and Forensic) were significantly poorer than that of the Control group; however, the mean performances of the Clinical and Forensic groups did not differ significantly from one another. Because all three groups were matched on years of formal education, and because no significant age effect was apparent within any of the three experimental groups, these demographic factors are not likely to be relevant to the *present* findings. Please note, however, that other studies involving verbal and figural fluency, using a broader cross section of age (i.e., many more older subjects) have found age a significant factor in performance (Benton & Hamsher, 1989; Daigneault et al., 1992; Mittenberg et al., 1989).

DISCUSSION

The first objective of this study was to determine if meaningful standardization data could be obtained for the "free condition" of Design Fluency. Contrary to the opinion of some authors (e.g., McCarthy & Warrington, 1990; Ruff et al., 1994), findings strongly suggest that the "free condition" of the Design Fluency task can be standardized for clinical use. Performances of control subjects were normally distributed without a "floor effect," and "blind" interrater reliability was high. The fact that the performance of the control sample in the present study correspond closely to the performances of normal control samples collected by Jones-Gotman and Milner (1977), Bigler (1995), Bigler et al. (1988), and Axelrod (1989) is also encouraging.

The second objective was to determine if Design Fluency had clinical utility in the assessment of head injured patients. Findings clearly demonstrate that Design Fluency can be useful in assessment of the head injured. Specifically, the data indicated that scores on the novel designs index of the "free condition" of the Design Fluency task is often impaired among patients referred for neuropsychological evaluation following closed head injury, this despite the fact that the patient sample was heavily weighted with so-called "minor" CHI patients who demonstrated relatively well-preserved general intellectual functioning.

Although novel design performance correlated significantly with Controlled Oral Word Association performance, the small size of this correlation suggests that Design Fluency is not merely an "alternate form" of the verbal fluency task. Similarly, the significant but very low correlation between Design Fluency and Digit Symbol demonstrates that failure in Design Fluency is not simply a reflection of poor concentration or diminished graphomotor speed. In this respect, findings are very similar to those obtained with regard to Figural Fluency, where relationships with Digit Symbol and Word Fluency were also weak (Ruff et al., 1987).

Scoring by error type proved to be of marginal clinical value with regard to nameable designs and of no clinical value with regard to perseverations or scribbling. At the same time, scoring of nameable responses proved of clinical interest in a number of individual cases and represented a significant fraction of total responses among the head injured but not among controls. Other studies have reported that perseverative errors may also be a significant variable in scoring with demented populations (Bigler, 1995).

Although the mean performances of the clinical and forensic samples did not differ significantly, the slightly increased frequency of defective performance in the nonforensic clinical sample generally runs counter to the argument that motivation for secondary gain was the sole (or a major) determinant of impaired performance in litigation related cases.

The fact that impairment in Design Fluency was not closely associated with diminished intelligence, weak graphomotor skills or impaired COWA underscores the practical clinical utility of Design Fluency in the assessment of patients with closed head injury. At the same time, this finding leaves open questions about the nature and prognostic significance of impaired Design Fluency in this and other clinical populations. Lezak (1993) suggests that Design Fluency, and its more structured counterpart, Figural Fluency, are measures of executive functioning. The findings of Jones-Gotman and Milner (1977) and Ruff et al. (1994) suggest a strong relationship between frontal damage and impaired Design Fluency. This is particularly relevant to the population under study given the frequency of anterior and inferior frontal damage among the head injured (cf. Gurdjian & Gurdjian, 1976; Jennett & Teasdale, 1981; Varney et al., 1995). However, given the variety of CNS injuries that can occur in association with CHI and the absence of positive CT or MRI data in this population, this hypothesis remains conjectural.

There has been and remains considerable controversy about whether patients with "mild" head injury can suffer lasting neuropsychological deficits. While such patients are less likely to have permanent residual impairments than patients with more severe injuries, it does not follow that all are free of permanent cognitive sequelae. Studies on the physics (cf. Varney & Varney, 1995) and neuropathology (cf. Lim, Chandran, Heath, & Unterharnscheidt, 1984) of mild head injury argue that some patients with "mild" brain injury can and should suffer lasting neuropsychological symptoms. Indeed, the present findings offer further evidence that impairment on selected tests can occur regularly among patients with "mild" head trauma, even when intelligence and memory testing is well within normal limits.

Given the findings on Design Fluency from Jones-Gotman and Milner (1977), Bigler (1995), Bigler et al. (1988), and the present study, along with Ruff's work on Figural Fluency (cf. Ruff et al., 1994), it can be argued that the production of novel designs within time constraints represents a promising set of neuropsychological assessment procedures with application in a variety of clinical populations. In addition, Design Fluency in the "free condition" can be readily included as part of the assessment of any nonagraphic patient because it requires only a pencil, blank paper, and a timer (along with published norms).

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