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Understanding design fluency: Motor and executive contributions

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Abstract

Design Fluency (DF) is typically assumed to assess planning, cognitive flexibility, and fluency in generation of visual patterns, above and beyond contributions from motor speed (Delis, Kaplan, & Kramer, 2001; Ruff, 1998). The present study examined these assumptions, as little construct validation research has been done in the past. Sixty one community-dwelling elderly participants were administered the DF, Trail Making, and Letter Fluency tests from the Delis-Kaplan Executive Function System (D-KEFS), as well as electronically administered measures of motor planning and motor sequence fluency. Hierarchical regressions were used to parse out unique variance contributions to DF performance. The results showed that generation of novel designs (i.e., the first two trials on the D-KEFS DF) relied primarily on motor planning, the ability to generate novel motor actions, and, to a lesser extent, speed of drawing with a writing implement. In contrast, generation of unique designs while switching (i.e., the third trial on the D-KEFS DF) relied primarily on visual scanning and perhaps visual-attentional resources. These findings highlight the wisdom of interpreting the switching trial of the D-KEFS DF separately. Interestingly, cognitive flexibility did not contribute to performance on any of the three D-KEFS DF trials. (*JINS*, 2010, *16*, 26–37.)

Keywords: Design fluency, Figural fluency, Motor planning, Cognitive flexibility, Executive function, Electronic tests, Motor action, Motor speed, Visual scanning, Construct validation

INTRODUCTION

Tests of Design Fluency (DF), also known as "figural" or "nonverbal" fluency, represent a method of assessment of executive functioning, commonly used in research and clinical settings. Examinees draw as many different designs as possible in one minute, while avoiding repeating prior designs. There are several versions of DF tests, most of which require that designs be drawn by connecting dots in a series of five-dot matrices (see Table 1 for a review of common DF tests). Given the general trend in clinical neuropsychology toward interpreting test results in terms of cognitive constructs, rather than lesion locations, understanding the cognitive underpinnings of DF performance is important. However, construct validation studies of DF have almost entirely relied on examining the neuroanatomic substrates of DF performance (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001; Butler, Rorsman, Hill, & Tuma, 1993; Elfgren & Risberg, 1998; Fama et al., 2000; Kramer et al., 2007; Suchy, Sands, & Chelune, 2003; Tucha, Smely, & Lange, 1999), with the assumption that sensitivity to frontal lobe pathology implies sensitivity to executive dysfunction.

A handful of studies that did examine the neurocognitive constructs that underpin DF performance have been summarized in the *RFFT: Ruff Figural Fluency Test Professional Manual* (Ruff, 1996). They suggest that, based on factor-analytic findings (Baser & Ruff, 1987), DF is a measure of "initiation, planning, and divergent reasoning" (p. 15), and that poor DF performance can*not* be explained by language, memory, or motor deficits (Ruff, Evans, & Marshall 1986). Beyond these empirical findings, the Delis-Kaplan Executive Function System (D-KEFS) version of DF (Delis et al., 2001) has been described as "fluency in generating visual patterns" (p. 88), likely based on the self-evident fact that "visual patterns" are the output of DF performance.

To examine the assertions that DF is a measure of (a) planning/initiation, (b) cognitive flexibility/divergent thinking, and (c) fluency in generating visual patterns, we recently conducted a study (Kraybill & Suchy, 2008) in which we used the Ruff Figural Fluency Test (RFFT; Ruff, 1998) as the dependent variable, and several motor and executive measures as predictors. Two of the motor variables used in that

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Table 1. Design Fluency tests overview

Design Fluency Measure	Number of Trials	Time per Trial	Background Matrix	Number of Lines	Distractors	Notes
Design Fluency	Two	4 min	None	Any (Trial 1) Exactly four (Trial 2)	None	n/a
Five-Point Test	One	5 min	Five dots	Any	None	n/a
Ruff Figural Fluency Test	Five	1 min	Five dots	Any	Trials 2 and 3	Trials 4 and 5 have asymmetrically positioned dots.
D-KEFS Design Fluency	Three	1 min	Five dots	Exactly four	Trials 2 and 3	Third trial requires switching between filled and empty circles

Note. Design Fluency (Jones-Gotman & Milner, 1977); Five-Point Test (Regard, Strauss, & Knapp, 1982); Ruff Figural fluency Test (Ruff, 1998), and D-KEFS Design Fluency (Delis, Kaplan, & Kramer, 2001).

study proved to be particularly useful in examining the construct of DF. These were “motor planning” and “motor fluency.”

Motor planning refers to the internal strategy that precedes an intended movement (Keele, 1981), and presumably contains both general information about the intended goal and specific information about the neuromuscular control that will be required (Keele, 1981). It was operationalized as the latencies prior to initiation of correctly executed sequences of specified hand movements using the *Push-Turn-Taptap* task from the Behavioral Dyscontrol Scale–Electronic Version battery (BDS-EV; Suchy, Derbidge, & Cope, 2005). In particular, participants learned four different sequences (or permutations) of three specified hand movements performed on a specialized response console (Figure 1). The task is described in more detail in Figure 2a.

Motor fluency refers to the ability to generate novel sequences of motor actions. It was operationalized as the total number of unique permutations of three specified hand movements produced on the BDS-EV *Motor Sequence Fluency* test. The Motor Sequence Fluency test uses the same response console (Figure 1) and the same hand movements as the Push-Turn-Taptap task used for assessment of *motor planning,* and is described in more detail in Figure 2b.

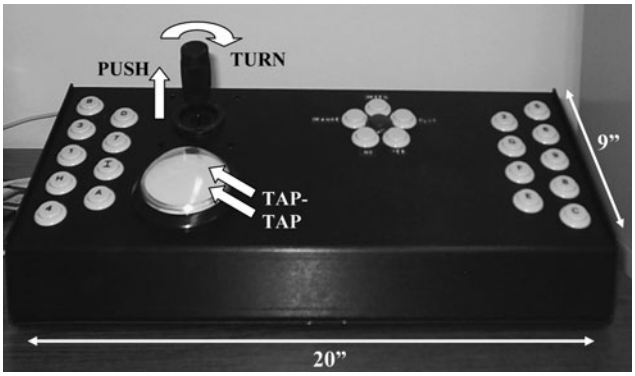

Fig. 1. The figure depicts the Behavioral Dyscontrol Scale–Electronic Version (BDS-EV) response console. It was used in the present study to assess Motor Planning and Motor Sequence Fluency.

In a series of hierarchical regressions designed to parse out unique and shared variances among the variables, the DF number of unique designs was predicted by (a) Trail Making Test-Part B (TMT-B), presumably reflecting cognitive flexibility, and (b) the two motor variables described earlier, *motor planning* and *motor fluency*. Together, these findings supported the prevailing conceptualization of DF as a test of cognitive flexibility and planning (even if just planning of motor actions) (Delis et al., 2001; Ruff, 1998). Additionally, these findings introduced the notion that DF may rely on fluency in generating motor actions, in addition to “fluency in generating visual patterns” (Delis, 2001; p. 88). Finally, consistent with prior findings (Ruff et al., 1986), motor speed, assessed via finger tapping, did *not* contribute to performance.

However, several questions remained. First, it was *not* clear whether the association between DF and TMT-B was a reflection of shared cognitive flexibility, or a reflection of shared component skills (i.e., visual scanning, motor speed, sequencing). The latter explanation would be consistent with the assertion of Delis and colleagues (2001, p. 89) that the Visual Scanning and Motor Speed conditions of the D-KEFS version of trail making can be used to assess component skills in DF performance.

Second, although we replicated previous findings that finger tapping speed was *not* related to DF performance (Ruff et al., 1986), it was still possible that *graphomotor* skills (i.e., the successful wielding of a writing implement) may contribute to the number of generated designs, as suggested by Delis and colleagues (2001, p. 89).

Third, while our prior study found that performance on the Motor Sequence Fluency test uniquely and significantly contributed to DF performance, it was *not* clear whether this relationship was due to some *general* fluency ability (i.e., one that would be shared by all fluency measures, both verbal and nonverbal), or whether it was *specific* to fluency in the *motor* domain.

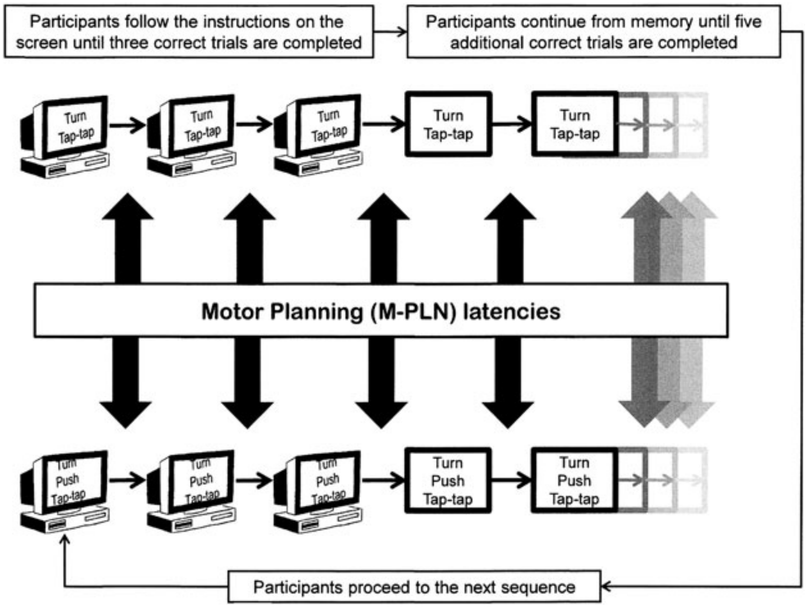

Fig. 2a. The BDS-EV Push-Turn-Taptap task requires that participants learn different sequences (or permutations) of three specified hand movements, using a specialized response console (Figure 1). The three hand movements are "Push" – pushing the joystick forward; "Turn" – turning the joystick clockwise; and "Taptap" – double-tapping on the white dome of the response console. The task begins by presenting a two-movement sequence on the computer screen, until three *correct* trials are completed. Following these three learning trials, participants continue to perform the sequence from memory, until accomplishing five additional *correct* trials. After completing the five correct trials, a new sequence is presented on the screen, and the just described process is repeated. There is a total of four different progressively longer sequences that participants learn in the course of this task (only the first two sequences are presented in this figure). Mistakes are followed by an audible tone, along with a presentation of the correct sequence on the screen. Motor Planning (M-PLN) latencies are indicated in the figure by the thick black vertical arrows, and reflect the preparation time before initiation of each trial. Only latencies preceeding correctly executed trials are included.

The purpose of the present study was to address these issues by replicating and extending our prior research. To that end, we administered a battery of cognitive and motor tasks to a sample of community-dwelling elderly. To tease apart cognitive flexibility and component skills, the present study employed the D-KEFS version of trail making (Delis et al., 2001), which includes not only alpha-numeric sequencing as a measure of cognitive flexibility, but also carefully designed control tasks that assess visual scanning, sequencing, and graphomotor speed. Additionally, to address the question of whether DF is related to *general* fluency abilities (*vs.* a *specific* fluency in generating *motor* sequences, as assessed via the Motor Sequence Fluency test), we included the D-KEFS Letter Fluency test in this study. Lastly, given that adequate construct validation requires a multi-method approach, the present study employed the D-KEFS version of DF, as opposed to the RFFT used in our prior study (Ruff, 1998).

METHOD

Participants

Participants were 61 right-handed, independently functioning community-dwelling elderly (62 % female). They were recruited from the community via advertisements and received $10.00 an hour for their time. University of Utah Institutional Review Board-approved informed consent procedures and the APA ethical guidelines were followed. See Table 2 for participant characteristics.

Instruments

Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). For all tests, standard administration and scoring procedures were followed unless otherwise noted. Untransformed raw scores were used as variables in analyses. The following three tasks from this battery were used:

The *D-KEFS Design Fluency (DF)* test consists of three trials in which participants create novel designs by connecting dots in a series of five-dot matrices. The three conditions are referred to as Filled Dots (connecting filled dots), Empty Dots (connecting empty dots while filled dots function as distractors), and Switch (switching between connecting filled and empty dots). The first two conditions are similar to the Ruff version of DF in that they assess DF both with and without visual distractors, whereas the third condition includes switching, which is *not* part of the Ruff version of the test. In the present study, the first two conditions and the third condition were examined separately, resulting in two DF variables: (a) The "Non-switch DF" score, comprised of the sum of correct unique designs generated during the first

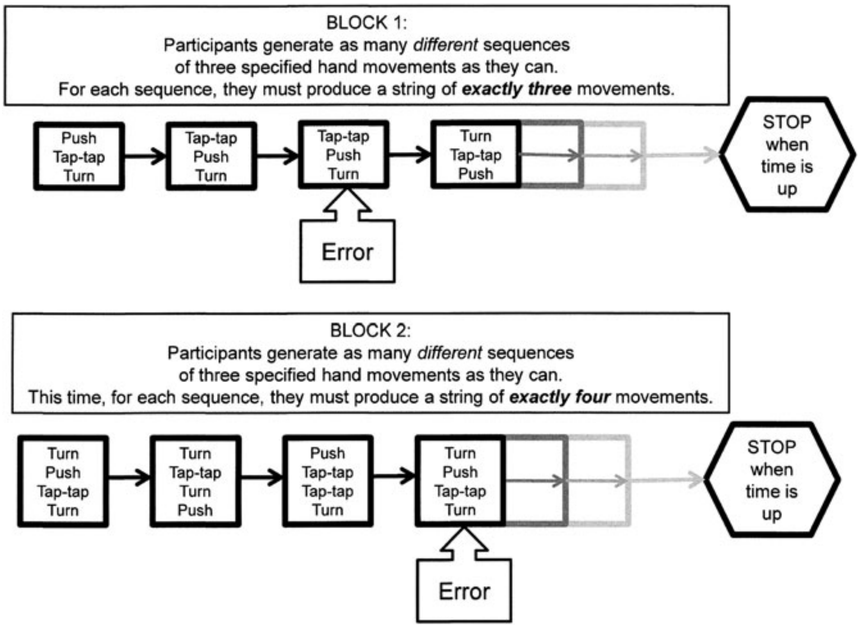

Fig. 2b. This figure depicts a hypothetical performance of a participant on the first two blocks of the Motor Sequence Fluency test. Participants are asked to generate as many unique sequences of three previously learned hand movements as they can. The movements are *push, turn*, and *tap-tap*, performed on the BDS-EV response console depicted in Figure 1. The test is organized into three blocks of progressively longer sequences, with the first block requiring that exactly three hand movements be strung together to create unique sequences, and the subsequent two blocks requiring that exactly four and five hand movements be strung together into sequences. Repetition of the same movements within a given sequence is permitted. However, repetition of the exact same sequence within a block constitutes an error. Only correct (i.e., unique) sequences are counted to generate the final score. The allotted time is individually determined based on participants' performance speed on the Push-Turn-Taptap task administered just prior to the Motor Sequence Fluency test.

two conditions; and (b) the "Switch DF" score, comprised of the total number of correct unique designs generated during the "switch" condition.

The *D-KEFS Trail Making Test* consists of five conditions: Visual Scanning, Number Sequencing, Letter Sequencing, Number-Letter Switching, and Motor Speed. All five conditions were administered. For all conditions, participants are asked to work as quickly as they can, and time to completion (in seconds) represents their raw score. The first four conditions present the examinee with a page of pseudo-randomly arranged circles containing letters, numbers, or both. Visual Scanning requires crossing-out circles that contain a particular number. Number and Letter Sequencing require connecting circles in the correct numerical or alphabetical order, respectively. Number-Letter Switching requires connecting circles in an alternating alphanumeric sequence. Motor Speed consists of circles that are already connected by a line, and participants use a pencil to trace the line as fast as they can. The D-KEFS Trail Making Test includes these five conditions so as to allow assessment of the speed of cognitive switching after visual, motor, and sequencing speeds have been accounted for.

For the purpose of this study, to isolate cognitive flexibility, we computed D-KEFS Number-Letter Switching residuals, after controlling for D-KEFS Visual Scanning, Motor Speed, and both Sequencing Speeds. Additionally, D-KEFS Visual Scanning and Motor Speed were examined in analyses as potential component processes of DF, as was previously recommended by Delis and colleagues (2001). Note that hereafter, the D-KEFS Motor Speed will be referred to as the D-KEFS Graphomotor Speed, so as to differentiate it from motor speed assessed in our prior study via finger tapping.

The *D-KEFS Letter Fluency Test* requires that participants generate as many words as they can that begin with a specific letter. The sum of the number of correct responses generated for three different letters (one minute each) represented the raw score used in analyses.

Behavioral Dyscontrol Scale-Electronic Version (BDS-EV; Suchy et al., 2005). The BDS-EV is an electronically

Table 2. Characteristics of the sample

	Mean	Standard Deviation	Range
Age	70.41	6.79	60–87
Education	14.51	2.72	10–22
M-DRS raw scores	137.92	5.34	117–144
M-DRS scaled scores	10.93	2.47	5–15

Note. $N = 61$. M-DRS = Mattis Dementia Rating Scale. Two participants (3.3% of the sample) had M-DRS scaled scores of 5 (moderately impaired range), and two had scores of 6 and 7 (mildly impaired).

administered battery of motor and executive tasks with excellent reliability (Suchy et al., 2005) and promising construct validity (Kraybill et al., 2009; Suchy et al., 2005; Suchy & Kraybill, 2007). Two tasks from the battery (i.e., the Push-Turn-Taptap task and the Motor Sequence Fluency test) were used in this study and are described next.

The *Push-Turn-Taptap* task generates variables that reflect various components of motor programming. However, for the purpose of this study, only the BDS-EV Motor Planning (M-PLN) variable was used, as it has been previously found to share unique variance with the number of unique designs generated during DF performance (Kraybill & Suchy, 2008). The M-PLN variable has been shown to have a strong relationship with executive functions (Kraybill, Suchy, & Franchow, 2009; Suchy & Kraybill, 2007). As seen in Figure 2a, the Push-Turn-Taptap task generates the M-PLN variable by measuring the amount of time (measured in milliseconds) that elapses between the completion of one repetition (or trial) of a given sequence and the initiation of the next correct repetition of that same sequence. Because there are four different sequences, and each sequence must be executed correctly eight times (i.e., three with computer prompts and five independently; see Figure 2a) before moving on to the next sequence, the M-PLN variable is based on a total of 32 planning latency observations.

The BDS-EV *Motor Sequence Fluency* test was administered immediately following the Push-Turn-Taptap task, using the same response console and the same three hand movements. Participants were asked to produce as many unique sequences (i.e., permutations) of the three hand movements as they could within an allotted amount of time. A hypothetical performance is depicted in Figure 2b.

Because the DF test gives all participants the same amount of time (1 minute per condition), whereas the Motor Sequence Fluency test automatically adjusts for participants' performance speed based on their performance speed on the Push-Turn-Taptap task, the two tasks needed to be placed on a comparable time allotment metric. This was done by computing an unstandardized residual score of the total number of generated unique motor sequences, after controlling for Push-Turn-Taptap performance speed. This score was used in analyses.

Statistical Analyses

All principal analyses in this study employed hierarchical regressions, using DF as the *criterion variable*. As described in the method section, the "Non-switch" and the "Switch" DF conditions were examined separately.

Predictor variables were selected and entered based on (1) the hierarchical model of cognition, according to which lower-order component processes (i.e., perceptual and motor functions) are governed by, and contribute to, higher-order control processes (i.e., executive functions) (Stuss, Alexander, Benson, Trimble, & Cummings, 1997), and (2) the assertions by Delis and colleagues regarding the nature of component processes presumed to contribute to DF performance (Delis et al., 2001; pp. 88–89).

Following this rationale, we first parsed out variance contributions from discrete *component* skills (i.e., D-KEFS Visual Scanning and Graphomotor Speed). Next, we examined contributions from *executive* processes *not* deemed specific to generative fluency (i.e., D-KEFS Number-Letter Switching residuals and the M-PLN variable from the BDS-EV). Lastly, we examined executive processes deemed *specific* to fluency performance (i.e., the BDS-EV Motor Sequence Fluency and the D-KEFS Letter Fluency). All analyses were conducted in sets of two, reversing the order of variable entries at consecutive steps, so as to allow partialing of *unique versus shared* variance contributions.

RESULTS

Preliminary Analyses

Descriptive statistics and zero-order correlations for all dependent and independent variables are presented in Tables 3 and 4, respectively.

Cognitive structure of the Non-switch Design Fluency (DF) condition

Contribution of D-KEFS Graphomotor Speed and Visual Scanning. D-KEFS Graphomotor Speed and Visual Scanning were entered on Steps 1 and 2, respectively, as well as

Table 3. Descriptive statistics for dependent and independent variables

Variable Type	Variable	Mean	Median	*SD*	Range
DV	Non-switch DF	19.23	19.00	5.54	8–33
	Switch DF	6.51	7.00	2.69	1–13
IV	D-KEFS Motor Speed	29.69	28.00	11.95	15–76
	D-KEFS Visual Scanning	27.44	25.00	10.64	16–90
	D-KEFS NLS residuals	112.21	95.00	52.02	40–240
	D-KEFS Letter Fluency	80.08	79.00	20.32	39–142
	BDS-EV Motor Planning	1044.19	1063.00	302.52	486.25–2170.5
	BDS-EV MSF	19.97	18.00	9.27	6–63

Note. N = 61. DV = Dependent variable; IV = Independent variable; DF = Design Fluency; D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; NLS residuals = Number-Letter Switching residuals; MSF = Motor Sequence Fluency.

Table 4. Zero order correlations among dependent and independent variables

Dependent Variables	Non-Switch DF	Switch DF
Age	−.295*	−.289*
Education	.061	.128
Sex	.303*	.212
D-KEFS Motor Speed	−.319*	−.259*
D-KEFS Visual Scanning	−.340**	−.439**
D-KEFS Number-Letter Switching residuals	−.245	−.234
BDS-EV Motor Planning	−.547**	−.416**
D-KEFS Letter Fluency	.423**	.230
BDS-EV Motor Sequence Fluency	.254*	.030

Note. $N = 61$. * $p < .05$; ** $p < .01$; Sex: 1 = female, 2 = male; DF = Design Fluency; D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version.

in the reversed order (i.e., Visual Scanning and Graphomotor Speed on Steps 1 and 2, respectively). Summaries of analyses are presented in Table 5, with the *italicized* numbers in the R^2 Δ column reflecting unique variance contributed by each variable. The results showed that Visual Scanning and Graphomotor Speed together yielded a statistically significant model, F (2, 58) = 5.18, p = .008, that accounted for 15.2% of variance in Non-switch DF (see column R^2 in Table 5, last Step in either analysis) with approximately 6.6% of Non-switch DF variance *shared* between Graphomotor Speed and Visual Scanning (i.e., total variance *minus* unique variance, or .152 *minus* the sum of the *italicized* numbers in the R^2 Δ column). However, Visual Scanning and Graphomotor Speed contributed *insignificant* amounts of *unique* variance (see p values in Steps 2 in the Table). Because of the significant contribution of the two variables together, both were entered on Step 1 of subsequent analyses.

Contribution of D-KEFS Number-Letter Switching residuals and BDS-EV Motor Planning (M-PLN). To determine whether the D-KEFS Number-Letter Switching residuals and/or the BDS-EV M-PLN contributed to performance above and beyond the D-KEFS Visual Scanning and Graphomotor Speed, we conducted another set of two hierarchical regressions, entering D-KEFS Visual Scanning and Graphomotor Speed on Step 1, and D-KEFS Number-Letter Switching residuals and the BDS-EV M-PLN variable on Steps 2 and 3, respectively, as well as in reversed order (i.e., M-PLN and Number-Letter Switching residuals on Steps 2 and 3, respectively). See Table 6 for summary of analyses (unique variance is *italicized*). Taken together, the results showed that the M-PLN variable *uniquely* contributed 11.9% of variance to Non-switch DF, with approximately an additional 4.2% of variance *shared* between M-PLN and D-KEFS Number-Letter Switching residuals. Unique contribution from D-KEFS Number-Letter Switching residuals was small (1.7%) and did *not* reach statistical significance. For that reason, M-PLN was the only variable added to the model in the next set of analyses.

Contribution of BDS-EV Motor Sequence Fluency and D-KEFS Letter Fluency. We first entered the three significant predictors from previous analyses (i.e., Graphomotor Speed, Visual Scanning, and M-PLN) on Step 1. Next, to determine whether the ability to generate novel designs depended on the ability to generate novel *motor* sequences *versus* the ability to simply *be generative* in any domain (even verbal), we entered Motor Sequence Fluency and Letter Fluency on Steps 2 and 3, respectively, as well as in the reversed order (i.e., Letter Fluency on Step 2 and Motor Sequence Fluency on Step 3). See Table 7. Taken together, the above analyses revealed that Motor Sequence Fluency and Letter Fluency each uniquely contributed 7.0% and 2.8% of variance, respectively, with virtually no overlap in variance (i.e., 1.2%). Only the contribution from Motor Sequence Fluency reached statistical significance, suggesting that it was a better predictor of Non-switch DF than was Letter Fluency.

The final model then included D-KEFS Visual Scanning and Graphomotor Speed, and BDS-EV M-PLN and Motor Sequence Fluency, which together accounted for 39.5% of variance, F (4, 56) = 9.15, p < .001.

Cognitive structure of the Switch Design Fluency (DF) condition

The statistical approach employed with the Non-switch DF (i.e., the order of variable entry, computation of unique *vs.* shared variance, etc.) was also employed when using the Switch DF as the criterion variable.

Table 5. Summary of hierarchical regressions reflecting variance contributions of Motor Speed and Visual Scanning to the number of Unique Designs generated in the first two trials of D-KEFS Design Fluency test

Step	Predictors	R^2	Adjusted R^2	R^2 Δ	F Δ	*df*	p value
1	D-KEFS Motor Speed	.102	.087	—	6.70	1,59	.012
2	D-KEFS Visual Scanning	.152	.122	*.050*	3.39	1,58	.071
1	D-KEFS Visual Scanning	.116	.101	—	7.73	1,59	.007
2	D-KEFS Motor Speed	.152	.122	*.036*	2.44	1,58	.123

Note. Italicized numbers in the R^2 Δ column reflect unique variance contributions. *df* = degrees of freedom. The Step 1 values in the F Δ column in reality represent F, not F Δ, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System.

Table 6. Summary of hierarchical regression reflecting variance contributions of Visual Scanning, Motor Speed, Cognitive Flexibility, and Motor Planningto the number of Unique Designs generated in the first two trials of the D-KEFS Design Fluency test.

Step	Predictors	R^2	Adjusted R^2	$R^2 \Delta$	$F \Delta$	*df*	*p* value
1	D-KEFS Visual Scanning D-KEFS Motor Speed	.152	.122	—	5.18	1,58	.008
2	D-KEFS NLS residuals	.212	.170	.060	4.35	1,57	.042
3	BDS-EV M-PLN	.330	.283	*.119*	9.93	1,56	.003
2	BDS-EV M-PLN	.313	.277	.162	13.44	1,57	.001
3	D-KEFS NLS residuals	.330	.283	*.017*	1.42	1,56	.238

Note. Italicized numbers in the $R^2 \Delta$ column reflect unique variance contributions. *df* = degrees of freedom. The Step 1 values in the $F \Delta$ column in reality represent F, not $F \Delta$, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; NLS residuals = Number-Letter Switching residuals.

Contribution of D-KEFS Graphomotor Speed and Visual Scanning. See Table 8 for a summary of the results. As can be seen, in contrast to Non-switch DF, Switch DF relied more on Visual Scanning, which contributed 13.1% of unique variance and an additional 6.7% of variance that was shared with Graphomotor Speed. This finding likely reflected the need to alternate between searching for filled and empty dots. Graphomotor Speed did *not* contribute unique variance to the model. Based on these results, we entered the D-KEFS Visual Scanning as the only predictor on Step 1 in the subsequent set of analyses.

Contribution of D-KEFS Number-Letter Switching residuals and the BDS-EV Motor Planning (M-PLN). The next set of analyses was conducted with D-KEFS Visual Scanning entered on Step 1, and D-KEFS Number-Letter Switching residuals and BDS-EV M-PLN entered on Steps 2 and 3 and *vice versa* (Table 9). The results showed that Number-Letter Switching residuals and M-PLN uniquely contributed approximately 2.9% and 3.6% of variance, with approximately an additional 2.5% of variance shared between them, for a total of 9.0% of variance above and beyond D-KEFS Visual Scanning. Although neither variable contributed significantly alone, they contributed significantly together, and thus were both added to the model in the next set of analyses.

Contribution of BDS-EV Motor Sequence Fluency and D-KEFS Letter Fluency. The next set of analyses was conducted with D-KEFS Visual Scanning, BDS-EV M-PLN, and D-KEFS Number-Letter Switching residuals entered together on Step 1, and BDS-EV Motor Sequence Fluency and D-KEFS Letter Fluency entered on Steps 2 and 3, and *vice versa* (Table 10). The results showed that, in contrast to Non-switch DF, neither Motor Sequence Fluency nor Letter Fluency contributed further to the model. The final model then included D-KEFS Visual Scanning, D-KEFS Number-Letter Switching residuals, and BDS-EV M-PLN, which together accounted for 28.3% of variance (Table 10, Step 1), suggesting that the Switch DF relied less on fluency than the Non-switch DF did.

Effects of demographic variables

As was done in our previous study, we examined whether demographic variables could account for the findings. Thus, we ran the two final models (one each for Non-switch DF and Switch DF), entering age, education, and sex on Step 1,

Table 7. Summary of hierarchical regression reflecting variance contributions of Visual Scanning, Motor Speed, Cognitive Flexibility, Letter Fluency, and Motor Sequence Fluency to the number of Unique Designs generated in the first two trials of the D-KEFS Design Fluency test

Step	Predictors	R^2	Adjusted R^2	$R^2 \Delta$	$F \Delta$	*df*	*p* value
1	D-KEFS Motor Speed D-KEFS Visual Scanning BDS-EV M-PLN	.313	.277	—	8.68	3,57	<.001
2	D-KEFS Letter Fluency	.354	.307	.040	3.47	1,56	.068
3	BDS-EV MSF	.423	.371	*.070*	6.65	1,55	.013
2	BDS-EV MSF	.395	.352	.082	7.57	1,56	.008
3	D-KEFS Letter Fluency	.423	.371	*.028*	2.66	1,55	.108

Note. Italicized numbers in the $R^2 \Delta$ column reflect unique variance contributions. df = degrees of freedom. The Step 1 values in the $F \Delta$ column in reality represent F, not $F \Delta$, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; MSF = Motor Sequence Fluency.

Table 8. Summary of hierarchical regressions reflecting variance contributions of Motor Speed and Visual Scanning to the number of Unique Designs generated in the Switch condition of D-KEFS Design Fluency test

Step	Predictors	R^2	Adjusted R^2	$R^2\ \Delta$	$F\ \Delta$	*df*	*p* value
1	D-KEFS Motor Speed	.067	.051	—	4.25	1,59	.044
2	D-KEFS Visual Scanning	.198	.170	*.131*	9.46	1,58	.003
1	D-KEFS Visual Scanning	.193	.179	—	14.07	1,59	<.001
2	D-KEFS Motor Speed	.198	.170	*.005*	.40	1,58	.531

Note. Italicized numbers in the $R^2\ \Delta$ column reflect unique variance contributions. *df* = degrees of freedom. The Step 1 values in the $F\ \Delta$ column in reality represent F, not $F\ \Delta$, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System.

and all the significant predictors identified in previous analyses on Step 2. The results showed that the previously identified predictors together accounted for 25.4% of variance in Non-switch DF above and beyond demographics, *F change* (4, 53) = 5.83, $p = .001$, and 18.4% of variance in Switch DF above and beyond demographics, *F change* (3, 54) = 4.73, $p = .005$. A summary of these models appears in Table 11.

Finally, while hierarchical regressions allow parsing out of unique variance contributions, they do not allow determination of the most parsimonious model (i.e., variables that are the *best overall* predictors). To provide that information, we present simple linear regressions in Table 12. As can be seen, BDS-EV Motor Sequence Fluency and M-PLN represented the two most prominent predictors for Non-switch DF, as was the case in our prior study. In contrast, D-KEFS Visual Scanning represented the single best predictor for the Switch DF condition.

Supplementary analyses

Our findings demonstrated that the Switch DF relied much more heavily on Visual Scanning than Non-switch DF did, presumably because of the need to visually separate empty and filled dots. However, the Non-switch DF itself contained data from two trials, one with filled dots only, and one with filled and empty dots (filled dots serving as distracters). To see whether this apparently slight difference reliably affected the degree to which Visual Scanning contributed to performance, we examined the contributions of D-KEFS Visual Scanning and Graphomotor Speed to *Trial 1* (Filled dots) and *Trial 2* (Filled and Empty dots) separately. The results showed that, as suspected, Trial 2 relied more heavily than Trial 1 on D-KEFS Visual Scanning. In particular, Visual Scanning contributed 5.4% of unique variance to Trial 2, as compared to 3.4% of variance to Trial 1. Graphomotor Speed contributed equally to Trials 1 and 2 (3.1% and 3.0%, respectively). These findings support the interpretation that the need to separate filled and empty dots may in part explain the increased Visual Scanning demands in the Switch DF.

DISCUSSION

Measures of Design Fluency (DF) represent a common component of neuropsychological batteries, both in clinical and in research settings. Although they are generally assumed to assess executive functions (primarily planning, cognitive flexibility, and fluency in generating visual patterns; Delis et al., 2001; Ruff, 1998), above and beyond motor speed (Ruff et al., 1986), relatively little empirical research has tested these assumptions.

In a recent construct validation study we examined these assumptions, finding that DF was related to: (a) BDS-EV Motor Planning (M-PLN), (b) TMT-B, presumed to measure cognitive flexibility, and (c) BDS-EV Motor Sequence Fluency test assessing the ability to generate novel motor sequence *without* generation of *visual patterns*. Additionally, DF was unrelated to finger-tapping speed. However, questions remained.

First, while motor speed assessed via finger-tapping appeared *unrelated* to DF performance, Delis and colleagues

Table 9. Summary of hierarchical regression reflecting contributions of Visual Scanning, Cognitive Flexibility, and Motor Planning to the number of Unique Designs generated in the Switch condition of the D-KEFS Design Fluency test

Step	Predictors	R^2	Adjusted R^2	$R^2\ \Delta$	$F\ \Delta$	*df*	*p* value
1	D-KEFS Visual Scanning	.193	.179	—	14.72	1,59	<.001
2	D-KEFS NLS residuals	.247	.221	.055	.21	1,58	.045
3	BDS-EV M-PLN	.283	.245	*.036*	2.85	1,57	.097
2	BDS-EV M-PLN	.254	.228	.061	4.779	1,58	.033
3	D-KEFS NLS residuals	.283	.245	*.029*	2.30	1,57	.135

Note. Italicized numbers in the $R^2\ \Delta$ column reflect unique variance contributions. *df* = degrees of freedom. The Step 1 values in the $F\ \Delta$ column in reality represent F, not $F\ \Delta$, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; NLS residuals = Number-Letter Switching residuals.

Table 10. Summary of hierarchical regression reflecting variance contributions of Visual Scanning, Cognitive Flexibility, Letter Fluency, and Motor Sequence Fluency to the number of Unique Designs generated in the Switch condition of the D-KEFS Design Fluency test

Step	Predictors	R^2	Adjusted R^2	R^2 Δ	F Δ	*df*	*p* value
1	D-KEFS Visual Scanning BDS-EV M-PLN D-KEFS NLS residuals	.283	.245	—	7.50	3,57	<.001
2	D-KEFS Letter Fluency	.286	.235	.003	.220	1,56	.641
3	BDS-EV MSF	.286	.221	*.000*	.000	1,55	.995
2	BDS-EV MSF	.283	.232	.000	.002	1,56	.969
3	D-KEFS Letter Fluency	.286	.221	*.003*	.215	1,55	.645

Note. Italicized numbers in the R^2 Δ column reflect unique variance contributions. *df* = degrees of freedom. The Step 1 values in the F Δ column in reality represent F, not F Δ, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; MSF = Motor Sequence Fluency; NLS residuals = Number-Letter Switching residuals.

(2001) nevertheless suggested that performance *can be* affected by motor speed "in drawing" (p. 89); thus, they recommended that D-KEFS Graphomotor Speed task (which assesses motor speed in drawing) be examined as a potential component skill of DF. Second, it was not clear from our prior study whether the association between DF and TMT-B reflected a common variance in cognitive flexibility, graphomotor speed, or visual scanning. And third, although we had found that BDS-EV Motor Sequence Fluency test contributed to DF performance, it was not clear whether this reflected *motor* fluency *in particular*, or fluency *in general*. The present study sought to address these questions.

The key findings of the present study were that generation of unique designs (i.e., the first two trials of D-KEFS DF) relied in part on: (a) D-KEFS Graphomotor Speed (in contrast to motor speed assessed via finger-tapping), (b) BDS-EV Motor Sequence Fluency test (as opposed to fluency *in general*), and (c) BDS-EV M-PLN. In contrast to previous assumptions, none of the three D-KEFS DF trials were substantially related to cognitive flexibility, as assessed with D-KEFS Number-Letter Switching residuals. D-KEFS Visual Scanning appeared related primarily to increases in the visual-attentional complexity of the task (i.e., addition of distractors), rather than generation of unique designs. Interestingly, Visual Scanning represented *the only* significant predictor of D-KEFS DF Switch condition.

Component Skills: Graphomotor and Visual Scanning Speeds

As suggested by Delis and colleagues (2001), D-KEFS Graphomotor Speed and Visual Scanning tasks both appeared to tap into component skills required for performance of Non-switch DF tests. Because our prior study failed to find a relationship between DF and motor speed (assessed via finger-tapping), it appears likely that the speed of wielding a

Table 11. Summary of final hierarchical regression models for the number of unique designs in the D-KEFS Design Fluency test

Criterion Variable	Step	Predictors	Adjusted R^2	R^2 Δ	F Δ	*p* value
Non-Switch DF	1	Sex Education Age	.097	.142	3.15	.032
	2	D-KEFS Motor Speed D-KEFS Visual Scanning	.142	.071	2.50	.091
	3	BDS-EV M-PLN	.334	.120	9.71	.003
	4	BDS-EV MSF	.396	.063	5.50	.023
Switch DF	1	Sex Education Age	.066	.113	2.43	.075
	2	D-KEFS Visual Scanning	.194	.134	9.98	.003
	3	D-KEFS NLS residuals BDS-EV M-PLN	.220	.050	1.93	.155

Note. $N = 61$. M-PLN = Motor Planning; MSF = Motor Sequence Fluency. The Step 1 values in the F Δ column in reality represent F, not F Δ, as they are the values for the base model. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; MSF = Motor Sequence Fluency; NLS residuals = Number-Letter Switching residuals.

Table 12. Summary of final linear regression models for the number of unique designs in the D-KEFS Design Fluency test

Criterion Variable	Predictor	*Beta*	*t*	*p* value
Non-Switch DF	Constant		2.20	.032
	Sex	1.205	.86	.393
	Education	.087	.36	.718
	Age	.048	.45	.653
	D-KEFS Visual Scanning	−.054	.77	.443
	D-KEFS Motor Speed	−.013	.21	.833
	BDS-EV M-PLN	−.009	3.65	.001
	BDS-EV MSF	.163	2.35	.023
Switch DF	Constant		2.693	.009
	Sex	−.120	.192	.849
	Education	.062	.366	.716
	Age	−.046	.872	.387
	D-KEFS Visual Scanning	−.275	2.019	.016
	D-KEFS NLS residuals	−.292	2.181	.177
	BDS-EV M-PLN	−.001	1.057	.295

Note. *N* = 61. D-KEFS = Delis-Kaplan Executive Function System; BDS-EV = Behavioral Dyscontrol Scale–Electronic Version; M-PLN = Motor Planning; MSF = Motor Sequence Fluency; NLS residuals = Number-Letter Switching residuals.

writing implement is what contributed to DF performance. However, the contribution of D-KEFS Graphomotor Speed to performance was relatively small, with less than 5% of unique variance accounted for. Thus, graphomotor abilities likely have minimal impact on performance, except among individuals with considerable graphomotor deficits.

In addition to Graphomotor Speed, D-KEFS Visual Scanning also contributed to test performance, and this contribution appeared to be a function of increases in the complexity of the visual and attentional demands of different DF conditions. In particular, Visual Scanning accounted for 3.4% of unique variance on Trial 1 (i.e., filled dots only), 5.4% on Trial 2 (i.e., filled dots functioning as distracters), and 13% on Trial 3 (i.e., switching between empty and filled dots). Moreover, as can be seen in Table 12, Visual Scanning represented the best *single* predictor of the Switch DF condition, accounting for nearly 20% of variance overall (Table 9). These findings suggest that the D-KEFS Visual Scanning contribution taps into the skills needed for *separation* of relevant and irrelevant visual stimuli: That is, the filled and empty dots on the D-KEFS version of DF (used in this study), and, likely, dots and distractors in the latter trials of the RFFT (Ruff, 1996) version of DF.

Executive Functions: Planning and Flexibility

As was the case in our prior study, BDS-EV M-PLN again emerged as a powerful predictor of the ability to generate novel designs (i.e., the first two conditions of D-KEFS DF), accounting for 12% of unique variance above and beyond component skills (Table 5), and represented the strongest single predictor (Table 12). In contrast, flexibility, at least as assessed by the residual score from D-KEFS Number-Letter Switching (after controlling for D-KEFS Graphomotor, Visual Scanning, and Sequencing Speeds), failed to account for a meaningful amount of variance in the first two D-KEFS DF conditions (i.e., less than 2%, see Table 6). This finding clarified that the association between cognitive flexibility and DF seen in our prior study was simply a function of the association between DF and component skills. Although contributions of flexibility increased somewhat when the switching demands were added to the task, the unique variance accounted for was still quite minimal (about 3%, Table 9). Together, these findings suggest that planning of a motor response (assessed via BDS-EV M-PLN), but *not* cognitive flexibility, may represent one of the key executive processes assessed by DF.

"Motor planning," the type of planning assessed by the BDS-EV M-PLN variable, is a covert aspect of complex motor output that can be thought of as the process of preparation for a movement prior to the movement initiation (Keele, 1981). Thus, it reflects planning at the level of immediate motor action. Although M-PLN latencies have been shown to be related to executive abilities (Suchy & Kraybill, 2007), it is not clear whether they are related to the more purely cognitive planning skills that do not involve immediate motor output.

Fluency: Specific versus General Construct

The present findings replicated our prior results (Kraybill & Suchy, 2008), again demonstrating that the Motor Sequence Fluency test was a unique predictor (Table 7) of the number of generated designs (i.e., the first two conditions of D-KEFS DF), even after demographics and other aspects of motor performance (i.e., M-PLN, Graphomotor Speed) have been accounted for (Table 11). Additionally, together with BDS-EV M-PLN, the BDS-EV Motor Sequence Fluency test represented one of the two strongest predictors of the Non-switch DF overall (Table 12). Incidentally, these same two variables emerged as the two strongest predictors of DF in our prior study as well (Kraybill & Suchy, 2008).

Moreover, the results confirmed that specifically *motor* fluency (i.e., the ability to generate novel motor actions), *not* fluency *in general*, predicted DF performance. This was demonstrated by the lack of association between Letter Fluency and DF. In particular, if the ability to generate novel designs relied on some general fluency ability (a construct that is sometimes invoked as a componential aspect of executive abilities), then this general ability would have to share variance with all three fluency tasks. However, that was not the case.

Switch DF Condition

The results showed that by adding the Switch condition, the cognitive structure of the D-KEFS DF task changed dramatically. As the Switch demand was introduced, performance appeared *unrelated* to BDS-EV Motor Sequence Fluency and M-PLN, both potent predictors of performance in the

Non-switch DF trials. These findings also suggest that switching may represent a construct that is: (a) separate from generative fluency, and (b) perhaps more heavily relying on attentional resources. These results provide support for considering the third (i.e., Switch) trial of D-KEFS DF as a separate construct when interpreting test results.

Limitations

Although our prior study, which yielded very similar results, was conducted with a sample that included the full adult life span (ages 18 to 68 years), it is not clear whether similar results would also be yielded by a sample of young healthy adults only, or by clinical samples, such as dementia patients, epilepsy patients, and so forth. In fact, different factor structures are known to emerge in different populations, particularly when it comes to timed (Psychological Corporation, 1997) and memory tests (Delis, Jacobson, Bondi, Hamiltoon, & Salmon, 2003). For example, timed visual-spatial tests generally load on a different factor than processing-speed tests, except among individuals in their eighties, for whom timed visual-spatial and processing-speed performances load on a single factor (Psychological Corporation, 1997). Similarly, while immediate and delayed recall on memory measures load on a single factor in most populations, they load on separate factors among individuals with mesial temporal dysfunction (Delis et al., 2003). Thus, it is possible that among a sample of patients with focal frontal lesions, cognitive flexibility would become dissociated from motor planning and would uniquely account for substantial variance in DF. These examples highlight the limitation of correlational methodology in construct validation research (Delis et al., 2003), and point to the importance of replications with other, preferably clinical, populations.

Additionally, as is usually the case, the present study yielded models that accounted for approximately between 30% and 40% of variance. This means that more than 60 % of variance remained unexplained. While some of the unexplained variance undoubtedly reflects random error, other systematic sources of variance could likely be identified. In particular, additional specific cognitive processes, such as working memory, attentional vigilance, and visual-constructional skills, may play a role. Similarly, differences in intellectual capacity could likely explain some variance, as Full Scale IQ is known to be differentially related to different cognitive tests (Psychological Corporation, 1997). Lastly, individual differences in temperament and personality, including motivation, autonomic arousal, state and trait anxiety, and interest and curiosity in new experiences all likely contribute differentially to performance (Williams, Suchy, & Rau, 2009). Including such a large number of variables would, of course, require a much larger sample.

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REFERENCES

Baldo, J.V., Shimamura, A.P., Delis, D.C., Kramer, J., & Kaplan, E. (2001). Verbal and design fluency in patients with frontal lobe lesions. *Journal of the International Neuropsychological Society*, *7*(5), 586–596.

Baser, C., & Ruff, R.M. (1987). Construct validity of the Sand Diego Neuropsychological Test Battery. *Archives of Clinical Neuropsychology*, *2*, 13–32.

Butler, R.W., Rorsman, I., Hill, J.M., & Tuma, R. (1993). The effects of frontal brain impairment on fluency: Simple and complex paradigms. *Neuropsychology*, *7*(4), 519–529.

Delis, D., Jacobson, M., Bondi, M.W., Hamilton, J.M., & Salmon, D.P. (2003). The myth of testing construct validity using factor analysis or correlations with normal or mixed clinical populations: Lessons from memory assessment. *Journal of the International Neuropsychological Society*, *9*, 936–946.

Delis, D., Kaplan, E., & Kramer, J. (2001). *Delis-Kaplan Executive Function System: Examiner's manual*. San Antonio, TX: The Psychological Corporation.

Elfgren, C.I., & Risberg, J. (1998). Lateralized frontal blood flow increases during fluency tasks: Influence of cognitive strategy. *Neuropsychologia*, *36*(6), 505–512.

Fama, R., Sullivan, E.V., Shear, P.K., Cahn-Weiner, D.A., Marsh, L., Lim, K.O., et al. (2000). Structural brain correlates of verbal and nonverbal fluency measures in Alzheimer's disease. *Neuropsychology*, *14*(1), 29–41.

Jones-Gotman, M., & Milner, B. (1977). Design fluency: The invention of nonsense drawings after focal cortical lesions. *Neuropsychologia*, *15*, 653–674.

Keele, S. (1981). Behavioral analysis of movement. In V.B. Brooks (Ed.), *Handbook of physiology*, Vol. *2*. *Motor control* (pp. 1391–1414). Bethesda, MD: American Psychological Society.

Kramer, J.H., Quitania, L., Dean, D., Neuhaus, J., Rosen, H.J., Halabi, C., et al. (2007). Magnetic resonance imaging correlates of set shifting. *Journal of the International Neuropsychological Society*, *13*(3), 386–392.

Kraybill, M.L., & Suchy, Y. (2008). Evaluating the role of motor regulation in figural fluency: Partialing variance in the Ruff Figural Fluency Test. *Journal of Clinical and Experimental Neuropsychology*, *30*(8), 903–912.

Kraybill, M.L., Suchy, Y., & Franchow, E. (2009, February). *Longitudinal prediction of functional independence and cognition: The utility of a brief motor programming task*. Poster session presented at the annual meeting of the International Neuropsychological Society, Atlanta, GA.

Psychological Corporation (1997). *WAIS-III & WMS-III technical manual*. San Antonio, TX: The Psychological Corporation.

Regard, M., Strauss, E., & Knapp, P. (1982). Children's production on verbal and non-verbal fluency tasks. *Perceptual and motor skills*, *55*(3), 839–844.

Ruff, R. (1998). *RFFT: Ruff Figural Fluency Test: Professional manual*. Odessa, FL.: Psychological Assessment Resources.

Ruff, R., Evans, R., & Marshall, L.F. (1986). Impaired verbal and figural fluency after head injury. *Archives of Clinical Neuropsychology*, *1*(2), 87–101.

Stuss, D.T., Alexander, M.P., Benson, D.F., Trimble, M.R., & Cummings, J.L. (1997). Frontal lobe functions. In *Contemporary* *behavioral neurology* (pp. 169–187). Woburn, MA: Butterworth-Heinemann.

Suchy, Y., Derbidge, C., & Cope, C. (2005). Behavioral Dyscontrol Scale–Electronic Version: First examination of reliability, validity, and incremental utility. *Clinical Neuropsychologist*, *19*(1), 4–26.

Suchy, Y., & Kraybill, M.L. (2007). The relationship between motor programming and executive abilities: Constructs measured by the Push-Turn-Taptap task from the BDS-EV. *Journal of Clinical and Experimental Neuropsychology*, *29*(6), 648–659.

Suchy, Y., Sands, K., & Chelune, G.J. (2003). Verbal and nonverbal fluency performance before and after seizure surgery. *Journal of Clinical and Experimental Neuropsychology*, *25*(2), 190–200.

Tucha, O., Smely, C., & Lange, K.W. (1999). Verbal and figural fluency in patients with mass lesions of the left or right frontal lobes. *Journal of Clinical and Experimental Neuropsychology*, *21*(2), 229–236.

Williams, P.G., Suchy, Y., & Rau, H. (2009). Individual differences in executive functioning: Implications for stress regulation. *Annals of Behavioral Medicine*, *37*, 126–140.