

# Evaluating the role of motor regulation in figural fluency: Partialing variance in the Ruff Figural Fluency Test

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Figural fluency is often thought to assess the ability to “think fluently and flexibly in the visual-spatial mode” (Ruff, 1988). However, the contribution of motor regulation to the performance of this task has not been previously examined. The goal of this study was to evaluate the potential relationship between motor sequence fluency (without a visual-spatial component) and figural fluency. A total of 55 participants (ages 18 to 68 years) were administered (a) the Ruff Figural Fluency Task (RFFT), (b) the Trail Making Test Part B (TMT-B), which overlaps with the RFFT in visual tracking and graphomotor demands, (c) an electronically administered Motor Sequence Fluency Test (MSFT), which overlaps with the RFFT in generation of novel hand movements in the absence of visual stimuli, and (d) a Complex Motor Programming Task. Hierarchical regression analyses were used to determine whether complex motor programming uniquely contributes to RFFT performance above and beyond the processes that are traditionally assumed to be required, as well as to determine whether the ability to generate novel motor sequences uniquely contributes to RFFT performance. Age and education were also added to the regression models in order to determine the contribution of demographic variables to the current findings. Results indicated that age, specific components of motor programming, and nonvisual motor generative fluency represent the most prominent predictors of RFFT performance. Consequently, the role of motor regulation and motor flexibility may in fact be more important for RFFT performance than previously thought, whereas visual-spatial processing may play a lesser role.

**Keywords:** Figural fluency; Motor programming; Executive function; Behavioral dyscontrol scale; Electronic tests; Frontal lobes; Motor action.

Tests of verbal and figural fluency are used to assess an aspect of executive functioning collectively referred to as generative fluency. When performing tests of verbal fluency, patients are required to generate words according to certain rules (e.g., words that begin with a certain letter), whereas figural fluency (also referred to as “design” or “nonverbal” fluency) is measured by asking patients to generate novel (i.e., nonrepetitive) abstract designs. Performance of both verbal and figural fluency tasks requires fluid and flexible thinking, self-monitoring, working memory, and the ability to inhibit repeating previously generated responses (Lezak, Howieson, & Loring, 2004). Given the tasks’ reliance on these processes, it is not surprising that both types of fluency rely at

least in part on the integrity of the prefrontal cortex (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001; Henry & Crawford, 2004; Reitan & Wolfson, 1994; Stuss & Benson, 1986).

In addition to their general association with the prefrontal cortex, fluency tasks have also exhibited sensitivity to hemispheric specialization, such that verbal fluency tasks have consistently been linked to the left hemisphere in general and the left frontal lobe in particular (Baldo et al., 2001; Benton, 1968; Costafreda et al., 2006; Hirshorn & Thompson-Schill, 2006; Kitabayashi et al., 2001; Milner, 1964; Ramier & Hecaen, 1970). Given that figural fluency is often thought to be a spatial analogue to verbal fluency, assessing the ability to “think fluently and flexibly in the visual-spatial mode”

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(Ruff, 1988, p. 2), it is often thought of as assessing the integrity of the right frontal lobe. However, the results of research on the laterality of figural fluency are mixed (Baldo et al., 2001; Suchy, Sands, & Chelune, 2003; Vilkki, Levanen, & Servo, 2002).

On the one hand, some older studies have demonstrated that patients with right frontal lobe lesions are impaired on figural fluency (Jones-Gotman, 1991; Jones-Gotman & Milner, 1977), and figural fluency has differentiated between patients with left or right frontal lobe lesions (Ruff, Allen, Farrow, Niemann, & Wylie, 1994). Additionally, quantitative electroencephalography has been used to show that figural fluency is sensitive to right frontal lobe functioning among healthy male college students with no history of significant head injury or cerebral dysfunction (Foster, Williamson, & Harrison, 2005). On the other hand, a number of more recent studies suggest that figural fluency tasks recruit both right and left prefrontal cortices, challenging the notion of the double dissociation between verbal/figural fluency and the left/right hemispheric functions (Baldo et al., 2001; Elfgren & Risberg, 1998; Suchy et al., 2003; Tucha, Smely, & Lange, 1999).<sup>1</sup>

One possible explanation for the bilateral involvement of figural fluency is that in addition to visual-spatial skills, motor programming (MP)<sup>2</sup> may represent a central element of performance. Similar conceptualizations have been proposed for other tests that involve visual-spatial stimuli. For example, motor (not visual-perceptual) perseveration is thought to represent the primary mechanism of poor test performance on certain paper and pencil tasks involving copying of stimuli, such as the rampart task that contributes to the initiation/perseveration factor on the Dementia Rating Scale (Mattis, 1976), or the Graphical Sequence Test (Jaeger, Goldberg, Bilder, & Podell, 1986; Lamar et al., 1997).

In terms of figural fluency, the designs that are generated as part of a figural fluency test require

that a patient draw and link together lines of different orientations and angles. Such activity clearly requires movement and as such relies on adequate functioning of the contralateral (i.e., for most people, the left) primary motor strip (Roland et al., 1980). In addition, however, successful figural fluency performance may also require much more complex MP processes, including motor planning (Keele, 1968), motor learning (Wolpert et al., 2001), and directional control of action (Whiting et al., 1992). Such reliance on complex MP would require substantial involvement of areas above and beyond the left primary motor cortex, including premotor, supplementary motor, and prefrontal areas (Haaland, 2006; Harrington & Haaland, 1991; Kawashima et al., 1993; Rushworth, Johansen-Berg, Gobel, & Devlin, 2003; Taylor & Heilman, 1980), primarily in the left hemisphere (Haaland, 2006; Harrington & Haaland, 1991; Hellige, 1993; Kawashima et al., 1993).

The goal of the present study was to evaluate the potential relative and unique contribution of complex MP to figural fluency. To that end, we examined whether performance on the Ruff Figural Fluency Test (RFFT; Ruff, 1988) is better accounted for by (a) Trail Making Test Part B (Adjutant General's Office, 1944), which differs from RFFT in terms of its left-hemisphere/verbal component, but is also similar to RFFT in terms of visual-spatial scanning, working memory, and cognitive flexibility (Eson, Yen, & Bourke, 1978; Lezak et al., 2004), or (b) performances on two electronically administered motor programming tasks (Suchy, Derbidge, & Cope, 2005), one assessing complex MP, including motor control, motor learning, and motor planning (Suchy & Kraybill, 2007), and the other assessing the ability to generate novel motor sequences in the absence of visual cues (Kraybill & Suchy, 2006). Contributions of these variables was assessed after controlling for simple motor speed using finger tapping.

## METHOD

### Participants

Participants were 55 healthy community-dwelling adults, age 18–68 years. Demographic characteristics of the sample can be found in Table 1. The sample used in this study was also used in a study that examined the initial validation of the Behavioral Dyscontrol Scale–Electronic Version (BDS-EV; Suchy et al., 2005). The results reported in this study do not overlap with those reported in Suchy et al. (2005).

<sup>1</sup>It should be noted that the above-mentioned studies make use of different versions of the figural fluency test. Even though these all seek to assess a common construct, there are minor differences in the administration and scoring of the various measures.

<sup>2</sup>Please note that MP includes, but is not limited to, the type of simple motor output that is known to activate the contralateral primary motor strip (Roland, Larsen, Lassen, & Skinhoj, 1980). In particular, MP refers to the complex sequencing and execution of motor actions, thought to consist of motor control (Whiting, Vogt, & Vereijken, 1992), motor learning (Wolpert, Ghahramani, & Flanagan, 2001), and motor planning (Wright, Black, Immink, Brueckner, & Magnuson, 2004).

**TABLE 1**  
Demographic characteristics of the sample

	<i>Mean</i>	<i>Median</i>	<i>SD</i>	<i>Range</i>	<i>%</i>
Age <sup>a</sup>	42.31	44.00	18.14	18–68	
Education <sup>a</sup>	14.92	15.00	2.13	12–21	
Female					49.1
Left-handed					16.4

<sup>a</sup>In years.

## Procedure

College-age participants volunteered to participate in the study in exchange for credit toward their introductory psychology course work. Older participants were recruited from the community via advertisements and were paid \$10 an hour for participation. Participants were tested one at a time in a quiet testing room.

Upon arrival, participants underwent standard institutional review board (IRB)-approved informed consent procedures. As part of a larger study, participants underwent testing using electronically administered tasks of MP and motor fluency and a brief battery of traditional neuropsychological tests, including Ruff Figural Fluency Test (RFFT) and Trail Making Test Part B (TMT-B). The entire session typically lasted approximately two hours.

## Instruments

### **Ruff Figural Fluency Test (RFFT; Ruff, 1988)**

Standard administration and scoring procedures were followed. Participants were presented with five pages, one at a time, and each page contained 35 five-dot matrices. They were instructed to connect two or more dots in each matrix, creating as many different designs as possible. Participants were allowed one minute on each of the five test pages. The RFFT is commonly used to assess figural fluency (Lezak et al., 2004) and relies on a variety of cognitive processes, including nonverbal capacity for fluid and divergent reasoning, initiation, ability to flexibly shift cognitive set in the visual-spatial mode, planning strategies, and the executive ability to coordinate this process (Ruff, 1988). Visual-motor speed and graphomotor speed also contribute to performance on the RFFT. The number of unique designs (UD) and the number of perseverative errors (PE) were used as variables in the analyses.

### **Trailmaking Test Part B (TMT-B; Adjutant General's Office, 1944)**

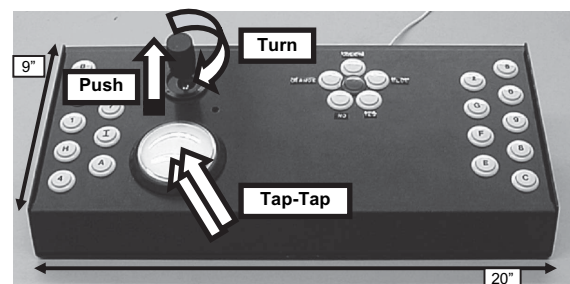
Standard administration procedures were followed. Participants were asked to draw a line connecting numbers and letters in an alternating sequence (i.e., 1A, 2B, etc.). This test overlaps with the RFFT in its reliance on visual-spatial mode and visual-motor speed, as well as working memory and flexibility demands (Banich, 2004; Eson et al., 1978). The total time to complete the task was measured in seconds, and this time was used in the analyses. Just like the RFFT, the TMT-B task has been shown to be related to frontal lobe integrity (Segalowitz, Unsal, & Dywan, 1992).

### **Finger tapping (FT)**

An electronic finger-tapping task was administered as part of the BDS-EV battery (Suchy et al., 2005). In this task participants are asked to use their index finger to tap a centrally located button on the BDS-EV response console as quickly as possible (see Figure 1). There are ten 10-second tapping trials, which use auditory cues to signal participants to start and stop tapping. Each trial alternates between the participants' dominant and nondominant hands. FT was used as a measure of simple motor speed.

### **Push–Turn–Taptap task (PTT)**

The PTT task is part of the BDS-EV battery (Suchy et al., 2005). In this task, participants are asked to learn four different sequences of three hand movements, using a specialized response console (see Figure 1). The three hand movements are as follows: (a) “push”—pushing the joystick forward, (b) “turn”—turning the joystick clockwise, and (c) “taptap”—double-tapping on the white dome of the response console. Participants start the first block of trials by learning a two-movement sequence, followed by blocks of three-, four-, and five-movement sequences. Each block begins with a presentation of the sequence on the computer



**Figure 1.** Response console.

screen, and the participant is asked to make the movements while the presentation is on the screen. After three correct sequences are accomplished, the screen presentation disappears, and participants are expected to perform the sequences from memory. Participants are aware from the beginning that the screen presentation will disappear after three correct trials.

If a mistake is made, an audible cue is presented, along with the correct sequence on the screen, with the movement on which a mistake occurred highlighted. Participants are asked to produce the highlighted movement (i.e., the movement on which they made a mistake) and then to proceed with the remainder of the sequence. Each block continues until five correct hand sequences are completed. However, the task is terminated if the criterion of five correct sequences is not achieved in 10 trials.

The PTT task can be used to measure three components of motor programming—namely, (a) motor control (M-CNT), (b) motor learning (M-LRN), and (c) motor planning (M-PLN; Suchy & Kraybill, 2007).

(a) *M-CNT*. M-CNT has been conceptualized as the ability to correctly produce discrete motor actions that can be either complex or simple (Whiting et al., 1992). Thus, as was done in our previous study (Suchy & Kraybill, 2007), we assessed M-CNT by assessing the participants' ability to perform a discrete and previously practiced movement (i.e., the double-tap) smoothly and correctly. In particular, our measure of M-CNT is a composite of (a) the median overall response latency between the two taps and (b) the overall number of perseverative responses (such as triple or quadruple taps) produced during the double-tap movement.

(b) *M-LRN*. M-LRN is thought to be the process by which a new task is successfully mastered. Before a task can be performed correctly it must be accurately learned. In the context of this study, participants must learn to perform various sequences of hand movements. Consequently, the accuracy of their performance, as measured by the number of errors committed, was used to assess M-LRN. Since, as previously mentioned, some errors may be the consequence of poor motor control, as opposed to inaccurate learning, we excluded the perseverative/control errors (i.e., triple and quadruple tapping) from the M-LRN variable used in the analyses.

(c) *M-PLN*. Finally, M-PLN has been described as an internal strategy that precedes an intended

movement (Banich, 2004). Prior to initiating a sequence of coordinated movements, an abstract plan is generated that contains both general information about the intended goal and specific information about the neuromuscular control that will be required (Keele, 1968). It has been shown that longer movement sequences require more planning time (Wright et al., 2004). Thus, to assess M-PLN, we measured the median amount of time (measured in milliseconds) that elapsed between the last movement of one sequence and the first movement of the next correct sequence. The elapsed time is believed to capture M-PLN. However, latency periods that preceded incorrect movements were excluded from subsequent analyses.

### **Motor Sequence Fluency Test (MSFT)**

The MSFT is administered in conjunction with the electronic version of the BDS-EV (Suchy et al., 2005). Participants are asked to use three different hand movements to generate novel sequences of three, four, and five movements (each in consecutive blocks of trials). Instructions are provided to perform each new sequence with a different combination of movements. The three hand movements are the same as those in the PTT task and include: (a) "push"—pushing the joystick forward, (b) "turn"—turning the joystick clockwise, and (c) "taptap"—double-tapping on the white dome on the response console (see Figure 1). The MSFT is always administered after the PTT task, as the speed of performance on the PTT task is used to calibrate the amount of time allotted for sequence generation. As such, this test only examines the ability to generate novel movements, unconfounded by motor speed or MP abilities. The MSFT overlaps with the RFFT in generation of novel motor sequences. However, these sequences do not result in a novel design, and as such are generated in the absence of visual-spatial stimuli or cues. Similar to the RFFT, MSFT generates two scores: (a) unique sequences (US), and (b) perseverative errors (PE).

## **RESULTS**

### **Preliminary analyses**

Means, medians, standard deviations, and ranges of all dependent and independent variables can be found in Table 2.

Zero-order correlations among dependent and independent variables can be found in

**TABLE 2**  
Descriptive statistics for dependent and independent variables

<i>Variable</i>	<i>Mean</i>	<i>Median</i>	<i>SD</i>	<i>Range</i>
RFFT-UD	106.24	108.00	22.96	48–155
RFFT-PE	12.60	9.00	12.95	0–62
Finger tapping	256.89	257.00	37.84	160–414
TMT-B	62.23	51.00	36.97	13–180
M-PLN	881.97	834.25	271.79	455.88–1,766.38
M-LRN	10.51	7.00	9.55	0–37
M-CNT	0.00	–0.22	1.00	–1.22–3.80
MSFT-US	19.96	19.00	6.45	3–39
MSFT-PE	1.89	1.00	2.78	0–17

*Note.* *N* = 55. RFFT-UD = Ruff Figural Fluency Test–unique designs. RFFT-PE = Ruff Figural Fluency Test–perseverative errors. TMT-B = Trail Making Test–Part B. M-PLN = motor planning portion of the Push–Turn–Taptap task. M-LRN = motor learning portion of the Push–Turn–Taptap task. M-CNT = motor control portion of the Push–Turn–Taptap task. MSFT-US = Motor Sequence Fluency Test–unique sequences. MSFT-PE = Motor Sequence Fluency Test–perseverative errors.

**TABLE 3**  
Zero-order correlations among dependent and independent variables

<i>Dependent variable</i>	<i>Independent variable</i>	
	<i>RFFT-UD</i>	<i>RFFT-PE</i>
Age	–.541**	.263
Education	.042	–.101
Handedness	.100	–.270*
Sex	.013	–.039
Finger tapping	.211	.106
TMT-B	–.584**	.381*
Motor planning	–.602**	.337*
Motor learning	–.337*	.466**
Motor control	–.335*	.353**
MSFT-US	–.105	.458**
MSFT-PE	–.184	.327*

*Note.* *N* = 55. To interpret the direction of correlations with handedness and sex note that handedness was coded as 1 = left and 2 = right; sex was coded as 1 = female and 2 = male. RFFT-UD = Ruff Figural Fluency Test–unique designs. RFFT-PE = Ruff Figural Fluency Test–perseverative errors. TMT-B = Trail Making Test–Part B. MSFT-US = Motor Sequence Fluency Test–unique sequences. MSFT-PE = Motor Sequence Fluency Test–perseverative errors.

\**p* < .05.  
\*\**p* < .01.

Table 3. As can be seen in the table, MSFT-US does not correlate with RFFT-UD. This is because in MSFT motor speed is already accounted for, such that each participant is allotted a different amount of time based on their speed of motor programming assessed earlier in the battery. In contrast, RFFT gives all participants an identical amount of time for test completion, regardless of their baseline motor speed.

**Contribution of motor control, motor learning, and motor planning to RFFT**

To determine whether complex motor programming, including M-CNT, M-LRN, and M-PLN uniquely contribute to the RFFT performance above and beyond the processes that are traditionally assumed to be required (i.e., simple motor speed, visual-spatial scanning, cognitive flexibility, and working memory), we conducted two hierarchical regressions (one using RFFT-UD and one using RFFT-PE as criterion variables), entering FT (i.e., simple motor speed) at Step 1, TMT-B (i.e., visual-spatial scanning, cognitive flexibility, and working memory) at Step 2, and all three components of MP (M-CNT, M-LRN, M-PLN) at Step 3. This analysis examined the contribution of complex MP to RFFT performance above and beyond other previously implicated processes

Next, again after first accounting for simple motor speed (i.e., FT), we reversed the order in which variables were entered, entering at Step 2 those MP components that contributed unique variance in the first set of analyses and entering TMT-B at Step 3. These analyses allowed a comparison of unique variance contributed by complex MP processes versus that contributed by processes assessed by TMT-B, above and beyond simple motor speed.

**RFFT unique designs (UD)**

Hierarchical regression analysis using RFFT-UD as the criterion, FT as a predictor at Step 1, TMT-B as a predictor at Step 2, and three components of MP (M-CNT, M-LRN, M-PLN) as predictors at Step 3 demonstrated that simple motor speed (i.e.,

FT) contributed minimally (i.e., 4.5% of variance) to the model,  $F(1, 53) = 2.48, p = .121$ . Additionally, as expected, visual-spatial scanning, working memory, and cognitive flexibility (i.e., TMT-B) accounted for approximately an additional 30.5% of variance,  $F_{\text{change}}(1, 52) = 24.34, p < .001$ , in RFFT-UD. Finally, M-PLN was the only MP variable that significantly contributed to the model above and beyond FT and TMT-B, accounting for approximately an additional 7.9% of variance,  $F_{\text{change}}(1, 51) = 7.01, p = .011$ . Reversing the order of variable entry (i.e., entering M-PLN at Step 2 and TMT-B at Step 3) demonstrated that M-PLN accounted for approximately 31.8% of variance above FT,  $F_{\text{change}}(1, 52) = 25.94, p < .001$ , and TMT-B alone contributed approximately an additional 6.5% of variance beyond that,  $F_{\text{change}}(1, 52) = 5.83, p = .019$ .

Taken together, the above analyses demonstrated that FT, TMT-B, and M-PLN together accounted for 42.8% of variance in RFFT-UD,  $F(1, 54) = 12.72, p < .001$ . Partialing of variance further revealed that approximately 23.9% of RFFT-UD variance was shared by both TMT-B and M-PLN, 7.9% was accounted for uniquely by M-PLN, 6.5% was accounted for uniquely by TMT-B, and 4.5% was accounted for by motor speed.

### **RFFT perseverative errors (PE)**

Hierarchical regression analysis using RFFT-PE as the criterion, FT as predictor at Step 1, TMT-B as a predictor at Step 2, and three components of MP (M-CNT, M-LRN, M-PLN) as predictors at Step 3 demonstrated that, again, FT did not contribute significantly (1.1% of variance) to the model,  $F(1, 53) = .060, p = .441$ . In contrast, TMT-B contributed significantly above and beyond FT, accounting for an additional 17.1% of variance,  $F_{\text{change}}(1, 52) = 10.88, p < .002$ . Finally, M-LRN was the only MP variable that significantly contributed above and beyond FT and TMT-B, accounting for an additional 9.0% of variance,  $F_{\text{change}}(1, 51) = 6.32, p = .015$ . Reversing the order of variable entry (i.e., entering M-LRN at Step 2 and TMT-B at Step 3) demonstrated that M-LRN accounted for 25.0% of variance,  $F_{\text{change}}(1, 52) = 17.64, p < .001$ , and TMT-B did not contribute significantly beyond that (1.1% of variance) to the model,  $F(1, 51) = 0.760, p = .388$ .

Taken together, the above analyses demonstrate that FT, TMT-B, and M-LRN together accounted for 27.3% of variance in RFFT-PE with approximately 17.2% of that variance shared by TMT-B and M-LRN, and M-LRN additionally uniquely accounting for 9% of variance. TMT-B and FT

accounted for negligible amounts (approximately 1% each) of unique variance.

### **Contribution of Motor Sequence Fluency Test (MSFT) to RFFT performance**

To determine whether the ability to generate novel motor sequences uniquely contributed to RFFT performance above and beyond the processes identified in the previous analyses, we conducted two additional hierarchical regressions, again using RFFT-UD and RFFT-PE as criterion variables. We entered all the significant predictors from the previous set of analyses on Step 1 and MSFT performance on Step 2.

#### **RFFT-UD**

Hierarchical analyses using RFFT-UD as criterion, TMT-B and M-PLN at Step 1, and MSFT-US at Step 2 demonstrated that MSFT-US accounted for approximately an additional 5% of variance above and beyond the original model,  $F_{\text{change}}(1, 51) = 5.31, p = .025$ , suggesting that the ability to generate novel motor programs in the absence of visual cues contributes to performance on RFFT.

#### **RFFT-PE**

Hierarchical analysis using RFFT-PE as criterion, TMT-B and M-LRN at Step 1, and MSFT-PE at Step 2 showed that MSFT-PE did not account for any additional variance above and beyond the original model.

### **Effects of demographic variables**

Even though only age and handedness demonstrated a significant (albeit slight) zero-order correlation with independent variables (see Table 3), demographic variables could nevertheless potentially have moderating or mediating effects on the other predictors. To examine whether demographic variables (age, education, sex, and handedness) would moderate or mediate present findings, we ran two final hierarchical regressions (one each for RFFT-UD and RFFT-PE), entering all four demographic variables at Step 1 and all significant predictors identified in previous analyses at Step 2. The results showed that, for RFFT-UD, the previously identified predictors together accounted for nearly 19% of variance above and beyond demographics,  $F_{\text{change}}(3, 47) = 6.34, p = .001$ . Similarly, for RFFT-PE, the previously identified predictor also accounted for approximately an additional 12% of variance above and beyond demographics,

**TABLE 4**  
Summary of hierarchical regression models

Criterion variable	Step	Predictors	Adjusted $R^2$	$R^2 \Delta$	$F \Delta$	$p$ value
RFFT-UD	1	Age, education, sex, handedness	.299	.351	6.77	<.001
	2	TMT-B, M-PLN	.407	.122	5.77	.007
	3	MSFT	.469	.065	6.62	.013
RFFT-PE	1	Age, education, sex, handedness	.101	.168	2.52	.052
	2	TMT-B, M-LRN	.194	.116	3.87	.028

Note. RFFT = Ruff Figural Fluency Test. UD = unique designs. PE = perseverative errors. TMT-B = Trail Making Test-Part B; M-PLN = motor planning portion of the Push-Turn-Taptap task; MSFT = Motor Sequence Fluency Test; M-LRN = motor learning portion of the Push-Turn-Taptap task.

**TABLE 5**  
Summary of linear regression models

Criterion variable	Predictor	Beta	$t$	$p$ value
RFFT-UD	Constant	N/A	4.51	<.001
	Age	-.284	1.957	.056
	Education	.175	1.549	.128
	Sex	-.060	0.578	.566
	Handedness	-.054	0.516	.608
	TMT-B	-.265	1.876	.067
	M-PLN	-.387	2.648	.011
RFFT-PE	MSFT	.278	2.573	.013
	Constant	N/A	2.016	.049
	Age	.128	0.686	.443
	Education	-.147	1.066	.292
	Sex	-.051	0.403	.689
	Handedness	-.203	1.595	.117
	TMT-B	-.019	0.098	.922
	M-LRN	.398	2.345	.023

Note. RFFT = Ruff Figural Fluency Test. UD = unique designs. PE = perseverative errors. TMT-B = Trail Making Test-Part B. M-PLN = motor planning portion of the Push-Turn-Taptap task. MSFT = Motor Sequence Fluency Test. M-LRN = motor learning portion of the Push-Turn-Taptap task. N/A = not applicable.

$F_{\text{change}}(2, 48) = 3.87, p = .028$ . Summary of these final models can be seen in Table 4. Finally, Table 5 presents results of corresponding linear regressions, demonstrating the relative contribution of individual variables in a linear, nonhierarchical model. As can be seen, age, M-PLN, M-LRN, and MSFT represent the most prominent predictors, again demonstrating the importance of aspects of MP, as well as the fact that generation of novel movements, in addition to, or perhaps even instead of, envisioning novel abstract designs, plays a crucial role in RFFT performance.

## DISCUSSION

As previously stated, the goal of the present study was to evaluate the potential contribution

of complex motor programming (MP) to figural fluency. Given that figural fluency is often thought to be a spatial analog to verbal fluency, and because the right hemisphere is known to be associated with spatial information processing (Banich, 2004), figural fluency has been widely believed to be subserved by the right frontal lobe (Foster et al., 2005; Jones-Gotman, 1991; Jones-Gotman & Milner, 1977; Ruff et al., 1994). Foster and colleagues (2005) also suggested that figural fluency could be linked to right frontal lobe functioning using neurophysiological data but unfortunately these authors did not measure left hemisphere activity and as such were unable to provide a double dissociation. Recent studies have also challenged the association between figural fluency and right hemisphere functioning by demonstrating that figural fluency performance may actually recruit bilateral frontal regions (Baldo et al., 2001; Elfgren & Risberg, 1998; Suchy et al., 2003; Tucha et al., 1999; Vilkki et al., 2002).

One explanation for the bilateral involvement of figural fluency may be that in addition to visual-spatial demands, performance of the task relies on complex MP and its various subcomponents, above and beyond simple motor output. This in turn would lead to considerable involvement of the left frontal lobe. In particular, while simple right-handed movements rely on the left hemisphere's primary motor cortex (Haaland & Harrington, 1996; Porro et al., 1996), more complex MP has been found to involve left hemisphere (or bilateral) premotor, supplementary motor, and prefrontal areas (Haaland, 2006; Harrington & Haaland, 1991; Kawashima et al., 1993; Rushworth et al., 2003; Taylor & Heilman, 1980).

In the current study, we found that specific components of MP (i.e., M-PLN and M-LRN) were in fact significant predictors of performance on a figural fluency task (i.e., the RFFT), above and beyond (a) simple motor speed assessed by FT, (b) working memory and visual scanning assessed

by TMT-B, and (c) demographic characteristics such as age, education, gender, and handedness.

Specifically, the number of unique designs on the RFFT was particularly related to M-PLN. This is a rather intuitive finding, given that for each new design a new motor plan needs to be put in place. Thus, the amount of time it takes to plan is understandably related to the number of designs generated within an allotted time frame. Additionally, the number of perseverative errors on the RFFT was related to M-LRN. At first blush, this finding is somewhat less intuitive, as RFFT performance does not rely on the ability to learn a particular new sequence over a number of learning trials. However, M-LRN is not just a reflection of learning over time, but also of the ability to correctly produce novel sequences. Similarly for each new RFFT design, a novel sequence needs to be de facto learned. Thus, poor learning results in errors both on the MP task and on RFFT.

In addition to the relationship between RFFT and MP, we also found that MSFT, a task that requires generation of novel hand movements without a significant visual-spatial component, contributed to performance on the figural fluency task. The MSFT is very similar to the PTT task (used for assessment of MP in this study), the only difference being that the MSFT requires that movements be generated spontaneously, rather than in response to a model. Thus, one can assume that it is this additional demand for spontaneous generativity (or fluid and flexible thinking) that is reflected in the unique contribution of MSFT to RFFT (above and beyond MP). Relatedly, if one assumes that all fluency measures (including MSFT) share this requirement for fluid and flexible thinking, one might suspect that it is this aspect of the RFFT performance that was not fully captured by TMT-B, M-PLN, or M-LRN.

These findings have important implications for better understanding the relationship between executive functioning, motor programming, and generative fluency.

### **Executive functioning, motor programming, and generative fluency**

Executive functioning, motor programming, and generative fluency are partly distinct and partly overlapping constructs. In particular, executive functioning (EF) is a term that is used to describe a variety of complex processes and subprocesses that affect behavior (Elliott, 2003). Despite the fact that EF is not a unitary construct, it can be broadly understood as the way in which individuals monitor

and control both their thoughts and actions. Motor programming (MP) overlaps with the construct of executive functioning, since MP refers specifically to monitoring and coordinating motor behavior (Suchy & Kraybill, 2007). Consequently, it is possible that the executive aspect of both motor sequence fluency and figural fluency is mediated by MP. However, generative fluency in general (i.e., whether verbal or figural) is also commonly associated with EF due to more purely cognitive (as opposed to motor) demands on the executive system, such as fluid and flexible thinking, self-monitoring, and working memory (Lezak et al., 2004). Thus, it is also possible that motor sequence fluency relies on the same higher order cognitive processes as other generative fluency tasks. In other words, due to considerable overlap among these constructs, it is unclear whether the common underlying ability in RFFT and motor sequence fluency is motor programming, higher order cognitive abilities, or a combination of both.

The overlap among these constructs may also be further influenced by the novelty and/or complexity of a given task. In particular, executive abilities are virtually invariably invoked when tasks are novel or complex. For example, the novelty of a task (i.e., if a participant has never before been introduced to the task) will likely in and of itself increase the demand on executive processes. In fact, in our previous study (Suchy & Kraybill, 2007) we found that when a task is novel, executive processing is particularly important for effective M-PLN to take place. Although in the current study drawing a straight line between two dots may be a familiar motor task, generating unique motor patterns for each new design is likely not something participants would have done before. As a result, novelty is likely to affect the degree to which executive abilities contribute to the process of M-PLN needed for execution of both the RFFT and the MSFT.

In addition to task novelty, the complexity of a task is also likely to influence the degree to which these constructs overlap. This has again been demonstrated in our prior study, where all aspects of motor programming (i.e., M-CNT, M-LRN, M-PLN) became increasingly dependent on executive processes with increasing complexity (Suchy & Kraybill, 2007). With respect to RFFT performance, complexity becomes relevant in two ways: (a) with an increasing number of designs, the sequences must become more complex as the simple sequences are exhausted in order to avoid repeating motor patterns, and (b) distractor lines in the later trials of the RFFT increase the response selection options and consequently increase the complexity of the task demands.

## Motor Sequence Fluency Task (MSFT) and clinical implications

The present study utilized the MSFT to demonstrate that the ability to generate novel sequences of hand movements is related to performance on the RFFT. In fact MSFT contributed to RFFT performance even above specific aspects of motor programming. This finding suggests that both tasks may in fact tap into a core “generative” ability that all fluency tasks (including verbal fluency) may share. It may be worthwhile to consider the potential clinical utility of the MSFT, especially with older populations who may find the visual aspects of RFFT too demanding due to peripheral visual problems, for whom the fine motor dexterity required for RFFT may be compromised by peripheral motor problems, or who may have difficulty with verbal fluency tasks due to a verbal dysfunction.

In summary, there is (a) a less than clear-cut relationship between figural fluency and laterality, (b) overlapping relationships between generative fluency, motor programming, and executive functioning, and (c) a clear requirement of at least basic motor output for figural fluency performance, undoubtedly relying on left motor, premotor, and supplementary motor areas. The current study found that components of more complex motor programming (i.e., M-LRN and M-PLN) were significant predictors of performance on the RFFT and account for a unique proportion of the variance above and beyond variance accounted for by demographic variables, finger tapping, and Trail Making Test Part B. Consequently, RFFT performance can be understood as mediated at least in part by the contribution of these MP variables; motor regulation and motor flexibility may actually play a more important role in RFFT performance than previously thought.

## Limitations

The present study relied on a relatively small, nonclinical sample that was used in another study. However, these findings have not been reported elsewhere, and there was enough variance within our sample to generate statistically significant results.

This study also discusses neuroanatomic implications but does not utilize imaging techniques or participants with known lesions and as such cannot make specific claims regarding the neuroanatomic substrates involved in figural fluency. However, our limited discussion of neuroanatomy

is restricted to a theoretical discussion and is based on the current literature. Future studies may help further elucidate the role of complex motor programming in figural fluency task performance. Additionally, although the current study did not utilize functional neuroimaging techniques, our motor programming task is conceptually similar to other complex motor programming tasks used in functional neuroimaging research and as such is believed to recruit either left or bilateral primary motor, premotor, and prefrontal areas.

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