Neuromotor Functioning in Adolescents With Schizotypal Personality Disorder: Associations With Symptoms and Neurocognition

by Craig S. Neumann and Elaine F. Walker

Abstract

Previously, Neumann and Walker (1999) used a computerized motor assessment and found that adults with schizotypal personality disorder (SPD) displayed increased and more variable motor force compared to adults with other personality disorders or healthy controls. Using the same motor assessment, the current study examined whether an independent sample of adolescents with SPD manifested a similar pattern of motor dysfunction compared to adolescents with other Axis II disorders or those without a disorder. As predicted, the SPD group showed increased and more variable force compared to the other two groups, which did not differ on these measures. These same motor variables were correlated with negative symptoms, as well as perseverative responses on a card sorting test. The significant correlations between motor functioning and perseverative responses and negative symptoms support recent research suggesting that subcortical motor regions play a role in higher order cognition and negative symptoms. Differences as well as broad similarities in the pattern of motor findings between the adult and adolescent SPD studies are discussed.

Keywords: Adolescents, neuromotor, neurocognition, symptoms, schizotypal personality disorder.

did not differ in terms of motor force and force variability. Vrtunski et al. suggested that disturbances in force and force variability may be specific impairments of schizophrenia and an important area for investigation, given that increased RT is a nonspecific finding that can be due to a number of factors, such as normal aging, medical illness, and a number of psychiatric disorders.

Similar findings have been reported for adults with SPD. Using a computerized motor assessment similar to the one used by Vrtunski et al. (1989), Neumann and Walker (1999) found that adults who met criteria for SPD displayed increased and more variable motor force, compared to adults with as well as those without other personality disorders. Also, consistent with previous research (Caligiuri and Lohr 1994), increased force instability was associated with increased positive symptoms as well as negative symptoms (Neumann and Walker 1999). The association with negative symptoms may have occurred, in part, because the motor task had a cognitively based choice RT component.

In sum, the findings suggest that specific indexes of motor dysfunction (e.g., excessive and more variable/unstable force), as opposed to slowed RT, may represent unique features of SSDs and perhaps can help in elucidating other aspects of this spectrum of disorders.

In addition to being an important precursor and correlate, neuromotor dysfunction may be critical for understanding other fundamental features of SSDs (Walker 1994; Neumann and Walker 1995, 1999; Walker et al. 1999). Indeed, there is a growing body of literature that suggests that neuromotor function is associated with the cognitive (Dreher et al. 1999; D’Reaux et al. 2000), biochemical (Neumann and Walker 1999; Walker et al. 1999), and social and emotional disturbances (Fish et al. 1992; Dworkin et al. 1993; Walker et al. 1994, 1996; Neumann et al. 1995, 1996) in SSDs. More recently, Silver and Shlomo (2001) reported that motor functioning in schizophrenia was associated with the ability to identify facial expressions of emotion.

Walker and colleagues have been investigating the links between neuromotor functioning and other aspects of schizophrenia. Using a novel longitudinal design that incorporated home movies coded for neuromotor functioning (Walker and Lewine 1990; Walker et al. 1994) and facial affect (Walker et al. 1993) in conjunction with parent reports of childhood behavior (Neumann et al. 1995) and adult clinical outcome data (Neumann et al. 1996; Walker et al. 1996), these investigators have been able to document how disturbances in neuromotor functioning are related to the childhood precursors and adult features of schizophrenia. For instance, Neumann and Walker (1995) found positive associations between early childhood neuromotor dysfunction and subsequent internalizing, social, and attention problems in preschizophrenia children. Also, severity of childhood behavior problems was associated with increased childhood neuromotor dysfunction (Neumann et al. 1995).

Extending these initial findings, subsequent studies showed that early neuromotor dysfunction was strongly correlated with increased ventricle-to-brain ratios in adult-onset schizophrenia (Walker et al. 1996) and that childhood preschizophrenia behavioral and attention problems predicted motor and cognitive dysfunction in adulthood (Neumann et al. 1996) as well as symptoms of schizophrenia in adulthood (Baum and Walker 1995). In support of the studies by Walker and colleagues, Dworkin et al. (1993) found that childhood neuromotor and attentional problems predicted deficits in affect and social functioning, respectively. Cannon et al. (1999) reported that disturbances in both motor and cognitive functioning at age 4 were significant predictors of an adult schizophrenia diagnosis.

Taken together, the findings indicate that neuromotor functioning across the life span is associated with the childhood precursors and the adult psychiatric and cognitive features of schizophrenia. Moreover, because motor dysfunction is known to precede the clinical onset of schizophrenia by many years (Walker et al. 1994), assessments of motor functioning hold promise for identifying individuals at increased risk (Neumann and Walker 1995; Cannon et al. 1999). Adolescence, in particular, may represent a critical time for identification of neuromotor problems given that this period of development is associated with the prodromal stage of major psychopathology.

The findings above linking neuromotor and neurocognitive functioning are particularly interesting because this association is consistent with new basic research in developmental psychology and neuroscience. For instance, Rosenbaum et al. (2001) reviewed how intellectual and motor skills are acquired in fundamentally similar ways and found that basic coordination and timing processes seem to be required for intellectual as well as motor skills. Relatedly, Lichter and Cummings (2001) outlined several frontostriatal systems that are involved in the integration of sensory and limbic phenomena and play an important role in appropriate motivational and motor responses. In particular, the striatal neurons are engaged in information processing about events that are anticipated but have yet to occur, and thus the striatum has been hypothesized to play a role as a goal selector for potential adaptive processes (Schulz 1995, as cited in Lichter and Cummings 2001).

Additionally, two separate research groups (Ashby et al. 1998; Ashby and Waldron 2000; Middleton and Strick 2000) have detailed how subcortical motor regions involved in neuromotor functioning also play important roles in cognitive processes associated with prefrontal cortical activity and thus are viewed as critical components of cortical-subcortical circuits. In particular, Ashby and Wal-
dron (2000) have developed a model of category learning that involves the basal ganglia. They proposed that the cortex, thalamus, and basal ganglia are components of two parallel loops that are involved in respective explicit and implicit category learning systems. Using the Wisconsin Card Sorting Test (WCST) to demonstrate how the anterior (explicit) system might work, they proposed that the prefrontal cortex and the anterior cingulate are involved in the selection of explicit cognitive rules (e.g., sorting rules) and that the switching process (e.g., from color to shape) is mediated by the basal ganglia (which feed back to the prefrontal cortex via the thalamus).

Consistent with the Ashby and Waldron (2000) model, D'Réaux et al. (2000) found that motor functioning assessed via the finger-tapping test (FTT) was strongly positively correlated with attention/working memory performance in healthy adults and patients with a diagnosis of schizophrenia. Similarly, Silver and Shlomo (2001) reported that FTT performance was significantly associated with the ability to identify different emotions conveyed in facial expressions. Finally, Muller et al. (2002) found that finger tapping was associated with both cortical and subcortical (i.e., basal ganglia) activation in healthy controls and schizophrenia patients; other investigators have shown that finger tapping is associated with basal ganglia volumes (Hokama et al. 1995). Thus, as proposed by Lichter and Cummings (2001), it appears that subcortical basal ganglia dysfunction is associated not only with disordered movement but also with intellectual functioning, mood, personality, and behavior.

The basic and clinical studies above also support theories by both Walker (1994) and Graybiel (1997) that the neural circuits implicated in SSDs include subcortical regions involved in motor planning and regulation (i.e., neuromotor functioning). Similarly, Vrtnaski et al. (1989) interpreted their findings of increased motor force instability as reflecting disturbances in basal ganglia functioning. Other investigators have documented deficits in motor synchronization and hypothesized that they had a subcortical origin (Manschreck et al. 1985). Finally, consistent with the proposals by Walker (1994) and Graybiel (1997), a number of additional investigators have proposed that regions of the brain that subserve motor functioning, particularly subcortical motor regions, may be involved in producing both the cognitive and psychiatric features of SSDs (Alexander et al. 1986; Frith 1992; Neumann and Walker 1995; Andreasen et al. 1998).

In summary, neuromotor dysfunction is a prominent feature of SSDs. Instrumental motor tasks may be particularly sensitive for measuring increased motor force and variable motor force, which have been shown to be associated with the symptoms of SSDs. In addition, these particular disturbances in neuromotor functioning may reflect problems in a neural circuit that includes the basal ganglia, and this subcortical region has been recently shown to play an important role in frontal-subcortical circuits associated with higher cognitive processes. Taken together, the findings suggest that disturbances in motor functioning should be involved in both the cognitive and symptom features of SSDs.

To date, no study has investigated whether adolescents who are at increased risk for development of psychopathology also manifest disturbances on instrumental tasks of neuromotor functioning. The current study is an attempt to replicate and extend the neuromotor findings reported in adults using a completely independent sample of adolescents with SPD. Based on the literature reviewed above, we predicted that adolescents with SPD, compared to adolescents with no mental disorder or other Axis II disorders, would show the same pattern of motor disturbance (increased and more variable motor force) that has been demonstrated in adults with either SPD or schizophrenia. We also expected that problems in motor functioning would be significantly correlated with the symptoms of SPD. Finally, relying in particular on the Ashby and Waldron (2000) model, we hypothesized that disturbances in motor functioning would be correlated with perseverations on a card sorting task.

Method

Participants. The current study is part of a larger program of research on the biological and behavioral aspects of SPD in children and adolescents (Walker et al. 1999; Weinstein et al. 1999; Diforio et al. 2000). Data from the current study, which is focused on neuromotor functioning in adolescents with SPD, have not been previously published. Participants were 53 children ranging in age from 12 to 18 (mean = 13.75, standard deviation [SD] = 1.76). All participants (including the controls) were recruited through announcements directed at parents. The announcement described the criteria for SPD in lay terms. There were three diagnostic groups: 15 with SPD, 16 with one or more other Axis II disorders, and 22 with no disorder. A detailed account of subject recruitment appears in a previous report (Diforio et al. 2000). The groups did not differ in terms of age (Tukey-HSD $p > 0.05$), proportion of males ($\chi^2(2) = 0.39$, $p > 0.05$), or race ($\chi^2(2) = 0.80$, $p > 0.05$) (note that the $2 \times 2$ chi-square tests were similarly nonsignificant). Table 1 contains descriptive statistics.

Diagnostic Procedures. Informed consent was obtained from both the parent and the child. Initial screens for potential participants were conducted with the parents over the phone. All participants who were screened and generally met inclusion criteria were invited to participate.
### Table 1. Sample characteristics

<table>
<thead>
<tr>
<th></th>
<th>Diagnostic Group</th>
<th>Significant differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPD</td>
<td>OD</td>
</tr>
<tr>
<td>Total n</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Males</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Females</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>14.26</td>
<td>14.25</td>
</tr>
<tr>
<td>SD</td>
<td>1.38</td>
<td>2.14</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>African-American</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Caucasian</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Hispanic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WISC–R estimated IQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.92</td>
<td>12.15</td>
</tr>
<tr>
<td>SD</td>
<td>3.42</td>
<td>3.36</td>
</tr>
<tr>
<td>SPD symptoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10.26</td>
<td>6.26</td>
</tr>
<tr>
<td>SD</td>
<td>1.43</td>
<td>2.12</td>
</tr>
<tr>
<td>Positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.13</td>
<td>1.75</td>
</tr>
<tr>
<td>SD</td>
<td>1.24</td>
<td>1.29</td>
</tr>
</tbody>
</table>

Note—HC = healthy control; OD = other Axis II disorder; SD = standard deviation; SPD = schizotypal personality disorder; WISC–R = Wechsler Intelligence Scale for Children–Revised (estimated intelligence composite of vocabulary and information subtests [scaled score]).

Only six adolescents failed to meet criteria, and this was a consequence of current medication or substance addiction. None of the parents of the adolescents met diagnostic criteria for any Axis I psychotic disorder.

At study entry, the child completed the Structured Clinical Interview for *DSM–IV* (SCID; First et al. 1996) questionnaires, with assistance of the examiner when needed. Next, a clinical interview using the SCID–II (Spitzer et al. 1990) was conducted with each adolescent participant. Neuromotor and neuropsychological assessments followed the interview. When indicated, the adolescent participants were interviewed to determine presence of Axis I disorders, although none met criteria for any Axis I diagnosis (Diforio et al. 2000). Each interview was videotaped and independently rated by two doctoral students in the Clinical Psychology Program at Emory University—each with systematic training in administering the SCID—to establish interrater reliability for participants’ Axis II diagnoses (Cohen’s kappa > 0.80). The few diagnostic discrepancies that occurred were resolved by consensus during a case conference with the second author. The majority of participants were involved in the study because their parents perceived them as having serious adjustment problems. Thus, the level of general impairment was quite notable. In particular, none of the subjects in either the SPD group or the other personality disorder group was perceived as showing appropriate social functioning.

Participants were classified as healthy control (HC), SPD, or other Axis II disorder (OD) (i.e., cluster B or C, in particular, obsessive-compulsive, borderline, and personality disorder not otherwise specified). Of those who completed the neuromotor task, 15 met *DSM–IV* criteria for SPD, 16 met criteria for another Axis II disorder, and 22 did not meet criteria for any *DSM–IV* disorder. See Diforio et al. (2000) for additional details on diagnostic procedures.

Intelligence was estimated using a composite of the vocabulary and information subtests from the Wechsler Intelligence Scale for Children–Revised (Wechsler 1991). The groups did not differ on this composite, using a one-way analysis of variance (F(2,50) = 2.66, p > 0.05). Table 1 contains composite subtest means and SDs.

### Measures

**Instrumental Motor Task.** The computerized motor task has been described in detail in a previous report (Neumann and Walker 1999). Briefly, this assessment of motor functioning utilizes pressure-sensitive buttons that are fitted to force transducers (A.L. Design, Buffalo, NY), so that analog signals from each response button are fed into a computer and stored. Sensitivity of the buttons is 1
centinewton. Buttons are firmly secured on a board, 12 inches from the edge of the table and with 12 inches between the buttons. A color monitor is located 6 inches behind the response buttons at eye level for the seated subject. The highly pressure-sensitive buttons control the color of two squares that are presented on the monitor, one above each button. Depression of the button to the “resting” threshold of 50 centinewtons of pressure (i.e., between 0.07 and 0.2 millivolts) is required to make its corresponding color box turn from green to blue. Blue means that the pressure is in the acceptable range, while red means that too much pressure is being applied and green means that too little pressure is being applied. Within each task, a response trial did not begin until the subject maintained appropriate prestimulus force for approximately 1 second. Responses were assessed with both unimanual and bimanual conditions.

The computer is programmed to emit a stimulus after the pressure threshold has been activated for 1 second. There is a brief series of practice trials prior to each task condition, and the series is repeated if necessary. Subjects are instructed to respond to the target stimuli as quickly as possible. Button pressure was amplified and converted to digital data via a Keithley A/D (analog-to-digital) converter. A response, which consisted of depression of the pressure-sensitive button, was defined by criterion and set at 2 SDs above the baseline pressure maximum (i.e., 0.2 + 2 SD millivolts). Pressure levels are recorded every 5 milliseconds, and the mean and SD of pressure are computed on-line. All force data presented here are in millivolts (1.0 millivolt equals approximately 1,300 grams or 2.87 pounds of pressure) (Neumann and Walker 1999). Figure 1 contains an example of response force for a single trial.

The task has two stimulus conditions. In the auditory condition, the subject is required to respond to prespecified target tones (high tones) in a series of randomly presented high and low tones generated by the computer. In the visual condition, the task requires a response to real words in a series of lexical stimuli that contains both words (e.g., “nut”) and nonsense syllables (e.g., “neb”). The lexical and auditory stimuli are presented for 3 seconds. Both stimulus conditions were designed to contain more target than nontarget stimuli.

Motor composites. Because our previous research (Neumann and Walker 1999) revealed no differences between the auditory and visual conditions for any of the motor indexes, data were aggregated across stimulus conditions. Seven motor composites are derived from the motor responses for both the left hand and the right hand: (1) mean force equaled the mean of applied force during a response to a target stimulus; (2) mean force variability equaled the SD of mean force during a response to a target stimulus; (3) motor overflow was indexed by the correlation between force exerted by the responding and nonresponding hands during a response on the bimanual conditions (the higher the correlation coefficient, the greater the force of the nonresponding hand in conjunction with the responding hand); (4) movement time (in milliseconds) equaled the time to move from the prestimulus button to the response button in the unimanual condition; and (5) reaction time (in milliseconds) equaled the time to respond to the target stimuli. Finally, (6) the total number of omissions and (7) the total number of commissions were recorded. Composites were derived by averaging across all individual trials. Our previous research (Neumann and Walker 1999) with this measure indicates that the neuromotor variables have adequate reliability (average alpha = 0.77)

Symptom scales. Symptom scales were empirically derived to measure positive and negative signs using items from the SCID—II interviewer ratings (1 = absent or false, 2 = subthreshold, 3 = threshold). That is, positive and negative symptom scales were derived via factor analysis of the current data and reliance on previously published empirical research. Item ratings were summed to obtain positive and negative symptom scores for all participants, including the HC group.

The negative symptom scale consisted of the following items: (1) no close friends or relatives; (2) odd, eccentric, or peculiar behavior or appearance; (3) odd speech; and (4) inappropriate or constricted affect. The positive symptom scale consisted of the following items: (1) ideas of reference; (2) excessive social anxiety; (3) odd beliefs or magical thinking; and (4) unusual perceptual experiences. Based on our previous research with SCID—II symptom scales (Neumann and Walker 1999; Diforio et al. 2000), each shows good internal consistency and appropriate convergent and discriminant item-to-total correlations.

Modified Card Sorting Test. The Modified Card Sorting Test (MCST), a simplified version of the WCST, is designed to reduce ambiguity in terms of the sorting principle during the test. Nelson (1976) modified the WCST by reducing the number of response cards via removal of ambiguous cards that shared more than one attribute with the stimulus cards. These changes allow the subject’s sorting strategy to be more easily inferred and allow the examiner to provide unambiguous feedback to the subject. Moreover, on the MCST, the examiner asks subjects to change the rule after six consecutively correct sorts. These modifications increase the degree of flexibility inherent in the test, which may be especially useful for evaluating problem-solving abilities in adult psychiatric patients as well as child and adolescent psychiatric patients. Other investigators have also relied upon
a modified card sorting test when conducting research with schizophrenia patients (Toone et al. 2000; Perry et al. 2001).

Like the WCST, the MCST measures abstract reasoning/concept formation and perseverative responding. Participants are required to sort cards according to unspecified, alternating principles (color, form, number) based on feedback provided by the examiner as to the correctness of each placement of a card. For the purposes of the current study, only perseverative responses and number of categories achieved are presented.

Finally, it is important to mention that the 53 participants for the current study were recruited as part of a previously published study by Walker and colleagues on MCST performance in adolescents; the study used a larger sample of 62 children with and without SPD (Diforio et al. 2000). The current sample is a subset of the larger sample of those individuals for whom motor data were available (nine subjects were not able to complete the motor task because of scheduling conflicts). Most important, the current sample of adolescents did not differ from those in the larger sample in terms of age, race, sex, symptoms, estimated IQ, or MCST (statistical results available upon request). The MCST variable is used in the current study solely for the purpose of testing its association with neuromotor functioning.

Results

Means and SDs for the motor variables are presented in Table 2. Findings from our previous research (Neumann and Walker 1999) and that of other investigators (Vrtunski et al. 1989) have documented that SPD and schizophrenia groups display disturbances in neuromotor functioning, particularly force and force variability, compared to both psychiatric and healthy control groups, and that the latter two groups do not differ on these neuromotor measures. Thus, the previous findings can serve as grounding from which a set of a priori predictions can be developed. Specifically, two planned orthogonal comparisons were developed to test (1) whether the SPD group differed from a linear combination of the other two groups (OD and HC), and (2) whether the OD and HC groups differed from one another.

The results for the first a priori comparison were as follows: the SPD group, compared to the linear combination of the other two groups, displayed increased mean force for both the left ($t(50) = 2.22, p < 0.05$) and the right hand ($t(50) = 1.89, p < 0.05$) as well as greater mean force variability for both the left ($t(50) = 2.54, p < 0.05$) and the right hand ($t(50) = 2.09, p < 0.05$). The SPD group also manifested increased movement time for the left hand ($t(50) = 1.90, p < 0.05$) and more total errors of omission.
Table 2. Motor variable means and SDs for adolescents with no personality disorder, schizotypal personality disorder, or other personality disorder

<table>
<thead>
<tr>
<th>Variables</th>
<th>HC</th>
<th>SPD</th>
<th>OD</th>
<th>Group differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean force LH (mV)</td>
<td>0.641</td>
<td>0.755</td>
<td>0.621</td>
<td>SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Mean force RH (mV)</td>
<td>0.817</td>
<td>1.011</td>
<td>0.913</td>
<td>SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Mean force variability LH (mV)</td>
<td>0.255</td>
<td>0.348</td>
<td>0.268</td>
<td>SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Mean force variability RH (mV)</td>
<td>0.356</td>
<td>0.446</td>
<td>0.369</td>
<td>SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Right motor overflow LH*</td>
<td>0.217</td>
<td>0.118</td>
<td>0.270</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Left motor overflow RH*</td>
<td>0.108</td>
<td>0.101</td>
<td>0.180</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Movement time LH (ms)</td>
<td>511</td>
<td>562</td>
<td>460</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Movement time RH (ms)</td>
<td>504</td>
<td>515</td>
<td>445</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Reaction time LH (ms)</td>
<td>733</td>
<td>782</td>
<td>676</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Reaction time RH (ms)</td>
<td>709</td>
<td>750</td>
<td>658</td>
<td>(SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Omissions total</td>
<td>1.09 (1.12)</td>
<td>1.58 (1.31)</td>
<td>0.78 (0.52)</td>
<td>SPD &gt; HC, OD</td>
</tr>
<tr>
<td>Commissions total</td>
<td>0.72 (0.38)</td>
<td>0.63 (0.53)</td>
<td>0.66 (0.59)</td>
<td>SPD &gt; HC, OD</td>
</tr>
</tbody>
</table>

Note.—HC = healthy control; LH = left hand response; OD = other Axis II disorder; RH = right hand response; SD = standard deviation; SPD = schizotypal personality disorder.

* Motor overflow was indexed by the correlations between pressure exerted by the responding and nonresponding hands. The higher the correlation, the greater the movement of the nonresponding hand in conjunction with the responding hand.

(t(50) = 2.00, p < 0.05). For the remaining motor variables, the first comparison was not significant: motor overflow, left hand t(50) = 1.59, p > 0.05, and right hand t(50) = 0.76, p > 0.05; movement time, right hand t(50) = 0.85, p > 0.05; reaction time, left hand t(50) = 1.39, p > 0.05, and right hand, t(50) = 1.27, p > 0.05; and total commissions, t(50) = 0.41, p > 0.05. Table 2 contains a summary of these results.

As expected, the results for the second planned comparison of the HC and OD groups were all nonsignificant for each of the motor variables.

Next, the associations of the neuromotor variables with the symptom and MCST variables were determined via Pearson correlations. As predicted, the neuromotor variables showed strong associations with both negative symptoms and perseverations on the MCST. Notably, the neuromotor variables were minimally related to IQ, except for RT (which is not unexpected, as is discussed in the introduction) (table 3).

Covariate and Partial Correlation Analyses. Although no significant group differences were found for age or estimated IQ, these measures did show some significant correlations with the motor and MCST variables. Thus, the same planned comparisons as above were rerun using age and the estimated intelligence composite as covariates.

The multivariate regression effect was not significant for age (F(11,39) = 1.17, p > 0.05) but was significant for the intelligence composite (F(12,38) = 3.76, p < 0.01). For the age covariate, the univariate results indicated that the following variables had significant relationships with age (beta weights in parentheses, p's < 0.05): mean force, left (0.31) and right hand (0.30). Thus, age was associated with increases in mean force.

The univariate results indicated that the following variables had significant relationships with the intelligence composite covariate: total omissions (-0.62); movement time, left hand (-0.33); and reaction time, left (-0.57) and right hand (-0.51). Not surprisingly, higher estimated intelligence was associated with decreased response times and fewer omissions.

Most important, the patterns of results for the contrasts were largely the same, with one minor difference. When the intelligence composite was used as a covariate, the contrast comparing the SPD group to the other two groups on number of omissions became nonsignificant, suggesting that the high number of omissions evidenced in the SPD group may have been due to somewhat lower estimated intelligence compared to the other two groups.

Finally, as has been shown in numerous studies, we found that negative symptoms were correlated with MCST perseverations (r = 0.42, p < 0.01), while positive symptoms (r = -0.10, p > 0.05) did not show a similar association. Also, the correlations between motor force variability and MCST perseverations, and motor force and force variability and negative symptoms, were highly significant (table 3). Thus, further examination of the interrelationships among these variables was explored using partial correlations. The partial correlation results were as fol-
Table 3. Motor variable correlations with MCST and positive and negative symptoms

<table>
<thead>
<tr>
<th></th>
<th>MCST categories</th>
<th>MCST perseverations</th>
<th>Negative symptoms</th>
<th>Positive symptoms</th>
<th>Estimated IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean force LH</td>
<td>0.02</td>
<td>0.12</td>
<td>0.43***</td>
<td>0.12</td>
<td>-0.05</td>
</tr>
<tr>
<td>Mean force RH</td>
<td>-0.12</td>
<td>0.20</td>
<td>0.50***</td>
<td>0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>Force variability LH</td>
<td>0.02</td>
<td>0.42***</td>
<td>0.45***</td>
<td>-0.19</td>
<td>-0.19</td>
</tr>
<tr>
<td>Force variability RH</td>
<td>-0.10</td>
<td>0.45***</td>
<td>0.40***</td>
<td>-0.07</td>
<td>-0.29*</td>
</tr>
<tr>
<td>Omissions total</td>
<td>-0.53***</td>
<td>0.35**</td>
<td>0.24*</td>
<td>0.01</td>
<td>-0.65*</td>
</tr>
<tr>
<td>Commissions total</td>
<td>0.05</td>
<td>0.06</td>
<td>0.00</td>
<td>-0.37**</td>
<td>-0.03</td>
</tr>
<tr>
<td>Movement time LH</td>
<td>-0.15</td>
<td>0.25</td>
<td>0.25*</td>
<td>0.20</td>
<td>-0.33**</td>
</tr>
<tr>
<td>Movement time RH</td>
<td>0.00</td>
<td>0.12</td>
<td>0.15</td>
<td>0.15</td>
<td>-0.14</td>
</tr>
<tr>
<td>Reaction time LH</td>
<td>-0.20</td>
<td>0.26*</td>
<td>0.18</td>
<td>-0.02</td>
<td>-0.52***</td>
</tr>
<tr>
<td>Reaction time RH</td>
<td>-0.21</td>
<td>0.30*</td>
<td>0.14</td>
<td>-0.03</td>
<td>-0.43***</td>
</tr>
</tbody>
</table>

Note.—LH = left hand response; MCST = Modified Card Sort Test; RH = right hand response.
* p < 0.05; ** p < 0.01; *** p < 0.001 (1-tailed)

Discussion

The current results show that adolescents with SPD manifest greater and more variable force than do adolescents with other Axis II disorders or healthy controls. These findings are consistent with our research with schizotypal adults (Neumann and Walker 1999) and with other investigations that have used instrumental assessments to study motor functioning in both medicated and nonmedicated schizophrenia patients (Vrtunski et al. 1989; Caligiuri and Lohr 1994). As such, increased motor force and more variable motor force appear to be both sensitive and specific characteristics of SSDs.

Interestingly, in an electromyograph (EMG) study of muscle fiber activity, Flyckt et al. (2000) found that motor unit potentials were increased in amplitude in schizophrenia patients, compared to matched controls. Also, Muller et al. (2002) showed that finger tapping was associated with overactivation of the basal ganglia in unmedicated schizophrenia patients, compared to medicated schizophrenia patients. Thus, excessive neuromotor activity in SSDs can be observed at both the behavioral and physiological levels.

Among a number of different studies, disturbances in neuromotor functioning have been found to be associated with cognitive functioning and psychopathology (Neumann and Walker 1995). Thus, investigators have been focused on the nature and origin of such disturbances. Earlier research with schizophrenia patients (Manschreck et al. 1985; Vrtunski et al. 1989) suggested that deficits in motor synchronization and stability reflected disturbances in subcortical motor regions. Furthermore, a number of current theories (Walker 1994; Graybeil 1997; Ashby and Waldron 2000; Middleton and Strick 2000; Lichter and Cummings 2001) have proposed that there may be a fundamental link between subcortical motor and prefrontal cortical areas in the control of cognitive functioning. Consistent with these ideas, recent research has found moderate to strong associations between measures of neuromotor and neurocognitive functioning in adult schizophrenia patients and healthy controls (D’Reaux et al. 2000; Manschreck et al. 2000; Silver and Shlomo 2001) and in adults with symptoms of attention deficit hyperactivity disorder (Neumann 2001). In the current study, we found that increased variability in neuromotor functioning was correlated with increased perseverations on a card sorting test. Such a link between neuromotor and neurocognitive functioning is supported not only by the clinical studies discussed above but also by basic research in developmental psychology (Rosenbaum et al. 2001) and neuroscience (Lichter and Cummings 2001).

Consistent with the literature reviewed above, we found that RT, a presumed motor variable, was highly related to intelligence, as evidenced by the correlational and covariate analyses. Not surprisingly, a significant cor-
Neuromotor Functioning in Adolescents

relation between RT and card sort perseverations became nonsignificant once covariance with intelligence was par
tialed out. In contrast, significant associations remained
between motor force variability and perseverations, even
after partialing out age and estimated intelligence, as well
as negative symptoms. Thus, the results suggest that neuromotor force and force variability in particular are linked
with higher order cognitive abilities and symptoms of
SSDs but are not redundant with general intellectual ability.

A subcortical motor region of particular interest in schizophre
nia research has included the basal ganglia, which have been previously shown to be involved in plan
ning various neuromotor functions (Graybiel et al. 1994).
However, Graybiel (1997) has proposed that the basal gan
glia are involved not only in motor planning but also in the
regulation of cognitive pattern generators associated with
action-oriented cognitions. Her proposal is based on the
identification of cortico-basal ganglia loops that link, for
example, the caudate nucleus with the prefrontal cortex
(Fuster 1989, as cited in Graybiel 1997). Furthermore,
Graybiel (1997) suggests that the basal ganglia might be
involved in the generation of schizophrenic symptoms,
given that they are linked with forebrain structures that are
involved in cognitive planning, motivating goal-directed
behavior, and monitoring intentions (see also Frith 1992;

Moreover, Ashby and Waldron (2000) have developed
a model of category learning that involves the basal gan
glia. These authors have proposed that cognitive switching
processes may be mediated by the basal ganglia (which
feed back to the prefrontal cortex via the thalamus). Our
current results provide fairly direct support for the Ashby
and Waldron (2000) model of category learning insofar as
our neuromotor measure reflects basal ganglia function
ning.

The Ashby and Waldron (2000) model and other
neural circuit models mentioned above may aid in hypoth
esizing how problems in motor-cognitive circuits (e.g.,
coordination or switching of thoughts) might result in both
the pathological symptoms (e.g., fixed delusions, avoli
tion) and the cognitive deficits involved in SSDs. For
example, if the striatum plays a role as a goal selector for
potential adaptive processes (Schultz 1995, as cited in
Lichter and Cummings 2001) or a regulator for action-orien
ted cognitions (Graybiel 1997), then a disturbance in
this subcortical region might result in a "disconnect"
between the goals represented in the prefrontal cortex and
the basal ganglia's selection of particular responses. From
a phenomenological perspective, individuals might experi
ence such a disconnection as a feeling that they are not
fully in control of their behavior or motivations.

In support of this neuromotor-neurocognitive discon
nection hypothesis, Maher (1993) proposed that delusional
beliefs stem from attempts to explain anomalous subject
ive experiences. Similarly, Möller and Husby (2000)
illustrated that the initial prodrome of psychosis in first
episode schizophrenia was characterized by disturbances
in the perception of self. The self disturbances were
related to losing control of cognitive and affective experi
ences. Finally, Klosterkotter et al. (1997, 2001) were able
to show that self-experienced disturbances in cognition,
perception, and action predicted the onset of schizophrenia
approximately 8–9.6 years later.

Moreover, to a limited extent, the current findings
may help in understanding possible links between motor
functioning and emotion. Specifically, investigators have
pointed out that cortico-striato-pallido-thalamic pathways
may play a role in linking motor, emotional, and cognitive
processes (Braff and Geyer 1990; Heimer 2000; Lichter
and Cummings 2001). Such hypothesized links are consis
tent with studies that have shown associations between
neuromotor dysfunction and anxiety/depression (Dworkin
et al. 1993; Neumann and Walker 1995; Walker et al.
1996) and affect recognition (Silver and Shlomo 2001).
The current findings of significant correlations between
motor force and force variability and negative symptoms
are consistent with the idea that dysfunction in fronto
subcortical circuits also involves disturbances in motiva
tional/emotional (i.e., limbic) processes, as well as cogni
tive and motor processes (Lichter and Cummings 2001).

The results also indicated that disturbances in motor
functioning were not significantly correlated with positive
symptoms. In our previous study of adults with SPD (Neu
mann and Walker 1999), we found that both positive
(mean r = 0.29) and negative symptoms (mean r = 0.32)
were correlated with increased and more variable force.
On the other hand, Caligiuri and Lohr (1994) found
that only positive symptoms were associated with force insta
bility. Notably, both of these previous studies used adult
cipients. Given that positive symptoms usually emerge
later in adulthood, it may be that our sample of young ado
lescents limited the possibility of detecting an association
between neuromotor functioning and positive symptoms.
Similarly, the limited variability in positive symptom
scores across groups limited the opportunity for associ
ations with neuromotor functioning. Interestingly, our pre
vious research with preschool schizophrenia children and their
healthy siblings found that neuromotor dysfunction was
significantly related to early childhood withdrawal behav
ior but was less related to thought problems (Neumann
and Walker 1995).

Caligiuri and Lohr (1994) proposed that their simple
assessment of steady-state motor force did not have a cog
itive component. Given that cognitive deficits tend to be
associated with negative symptoms, they proposed that
their neuromotor assessment tapped into a brain area more
likely associated with positive than negative symptoms. On the other hand, investigators must realize the impossibility of eliminating all cognitive components from any motor task (e.g., as in the Caligiuri and Lohr study, direction to squeeze a hand dynamometer creates some level of mental set/cognitive activation). Certainly, our instrumental motor task contained a cognitive component in that participants were required to determine if the stimuli were targets or nontargets. However, while RT was significantly associated with intelligence, motor force and force variability were only modestly related to intelligence. Thus, instrumental motor tasks that assess additional motor processes besides RT may hold promise in their ability to predict specific cognitive or symptomatic disturbances.

Some have suggested that voluntary motor disturbances observed with instrumental motor tasks can be interpreted as reflecting spontaneous dyskinesia (Caligiuri and Lohr 1994). Therefore, the excessive and more variable force observed in the current study may reflect aspects of involuntary dyskinesia. In support of this hypothesis, our previous research with this sample has found that the adolescents with SPD had higher rates of observation-based assessments of spontaneous dyskinesia than other adolescent groups did (Walker et al. 1999).

Comparing the findings from our previous study of adults with SPD (Neumann and Walker 1999) with the current results allows for some developmental considerations. First, compared to the adolescents' averages for mean force and force variability (figure 2), all the adult groups showed lower averages (e.g., right hand mean force, SPD = 0.769, OD = 0.552, HC = 0.597). Second, it is important to note that these differences were not due to differences in proportions of males and females between the adult and adolescent studies (i.e., the same pattern of differences remained across and within studies when examining the male and female motor data separately). Therefore, given that adolescence is a developmental period where psychopathology is in ascendance, the general increase in force and force variability could reflect increased risk.

Yet at the same time, the pattern of differences among the adult groups were generally the same as for the adolescent groups (i.e., SPD > HC, OD) with respect to mean force and force variability. To some extent then, there is consistency in the sensitivity and specificity of the findings across age groups. Thus, the general increase in force and force variability in the adolescents, compared to the adults, might reflect normative developmental phenomena. In support, other investigators have also documented a diminution of neuromotor problems with age (Gillberg et al. 1989; Soorani-Lunsing et al. 1993), which is likely due to the maturation of higher cortical regions (Neumann and Walker 1995).

Given that there is substantial evidence for discontinuity and diminution of neuromotor problems with development, the presence of neuromotor disturbance in adults might be viewed as more pathological than if seen in children. This hypothesis would help to explain the difference in findings between our adult study (Neumann and Walker 1999) and the current results with respect to motor overflow. That is, in the former study, motor overflow was greater in the adults with SPD than in the other two adult groups (see also Vrtunik et al. 1989). In the current study, motor overflow did not differ among the adolescent groups. Thus, certain signs of neuromotor disturbance may or may not be correlated with psychopathology given the age at which they are manifested.

Certainly, the differences in motor overflow between our adult SPD study (Neumann and Walker 1999) and the current adolescent SPD study could be explained by a number of hypotheses (e.g., differences in cortical maturation, white matter connectivities). However, in other research, we have found that preschizophrenia childhood neuromotor abnormalities were related to increased ventricle-to-brain ratios in adult-onset schizophrenia (Walker et al. 1996). Consistent with our previous findings, Thompson et al. (2001) have documented that neuromotor abnormalities in young schizophrenia patients are related to progressive gray matter tissue loss. Finally, both cognitive and motor impairments have been related to reduced cortical gray matter volumes (but not white matter volume) in adult schizophrenia patients (Sullivan et al. 1996). As such, the differences in motor overflow between the current adolescent SPD study and our previous adult SPD study (Neumann and Walker 1999) may be related to an underlying pathophysiology in cortical gray matter tissue loss; this pathophysiology could also involve disturbances in cortical control of subcortical regions such as the basal ganglia. In addition, the later emergence of positive symptoms, often conceptualized as neurological release phenomena, could also be explained in terms of reduced cortical gray matter and thus reduced cortical control of lower order systems.

In conclusion, neuromotor problems are clearly important indicators of nervous system integrity and an important area of research on SSDs (Walker 1994; Graybeil 1997; Andreasen et al. 1998). Meehl (1989) proposed that neuromotor signs are more direct manifestations of biological vulnerability than are cognitive and socioemotional factors. While this proposal may turn out to be true, it should also be recognized that early neuromotor problems predict later problems in affect regulation and cognition (Dworkin et al. 1993; Neumann and Walker 1995) and of course SSDs (Fish et al. 1992; Walker et al. 1994). Taken together, the findings suggest a causal relationship between SSDs and the cortical-subcortical circuits.
involved in both neurocognitive and neuromotor processes (and most likely, emotional processes as well). Because both neuromotor and neurocognitive disturbances predate the emergence of psychosis, disruptions in the relationship between these two domains may play a critical role in the eventual expression of SSDs. Thus, we hope that continued research on neuromotor functioning in schizophrenia and SPD and its relationship with cognitive and emotional processes will help clarify the nature of this spectrum of disorders.
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