In addition to tremors, akinesia, and rigidity, Parkinson’s disease is characterized by frontal cognitive dysfunction. The Stroop test is often used to assess the frontal lobe functions of neurological patients [1]. It consists of three tasks presented in a fixed order: word reading; color naming; and incongruent color-word-naming tasks in the Stroop test. Compared with the normal control group, the PD group had slower speeds for all three tasks and greater Stroop interference, indicating a response inhibition deficit in PD patients. Further analysis indicated that slowness during color naming might be due to motor slowness, rather than a central cognitive processing problem in color discrimination. In conclusion, the performance of the PD group on the three tasks of the Stroop test suggests that the PD patients were deficient in motor responses and cognitive inhibitory abilities.

Key Words: Parkinson’s disease, Stroop interference, Stroop test
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that the Stroop color-word test was sensitive to cognitive dysfunction in PD.

Overall, the evidence suggests that PD patients typically had a deficit of executive functions, such as inhibitory control or working memory updating, as indicated by their performance on the Stroop test.

However, executive dysfunction in PD patients can be coupled with and covered by increased motor slowing [7,8]. For instance, PD patients did not exhibit Stroop interference impairments even though PD patients were significantly slower than controls on all tasks [9]. Therefore, response slowness in the incongruent color-naming task could be confounded by a slowed response in the word reading and color naming tasks, which had little to do with dysfunction in inhibiting automatic word reading. Furthermore, the slow response times in the word reading and color naming tasks could be attributed to slowness in any stage in planning, initiating or executing motor responses [5], or in perceptual analysis of a stimulus [10]. The former stage involves motor programming and output, whereas the latter involves central cognitive processing. One method of examining each stage is using a subtraction approach. That is, subjects were administered two comparable tasks, which presumably differed by only one critical process, which was the focus.

In the Stroop color-word test, a subject is presented with a colored word that represents a different color. From a computational perspective, the Stroop color-word task requires a sequence of cognitive operations: (1) remember instructions to vocalize the ink color; (2) focus on the visual stimulus; (3) determine the ink color of the word; (4) inhibit naming of the words; and (5) make an appropriate response [11]. In reference to these stages of information processing, the reaction time for color-naming task requires the following steps: (1) focus on the visually presented stimulus; (2) determine the ink color; and (3) respond. Due to the automaticity of word reading, the reaction time for the word-reading task requires a subject to: (1) focus on the visually presented stimulus; and (2) respond. Using subtraction logic, the time necessary to determine the ink color is the difference between the times required to complete these two tasks.

When PD patient slowness is due to problems in cognitive central processing, the patient would have a slower time determining the ink color compared with normal controls. Otherwise, PD patient slowness might be caused by problems in the motor response. Using a choice reaction time task, it was found that PD patients had slowed central cognitive processing, and not slowed motor programming [10].

Specifically, this study attempted to test the following hypotheses. First, that slowness of PD patients during the Stroop color-word task would be attributable to a deficit in response inhibition rather than slow reading and naming; specifically, that the Stroop interference would be greater in PD patients than in controls. Second, we hypothesized that the slowness of PD patients in the color-naming task would be due to problems in central cognitive processing; specifically, that the decision time for the ink color would be longer in PD patients than in controls.

THE MATERIALS AND METHODS

Participants

Twenty-seven subjects with idiopathic PD (17 men, 10 women) from Kaohsiung Medical University Hospital (KMUH) were consecutively enrolled between July 2001 and June 2002. The mean duration of illness was 3.34±2.33 years. One patient did not complete the Stroop test because of color blindness. Diagnosis of PD was based on the presence of two or more clinical signs, such as bradykinesia, gait disturbance, rigidity and tremors. No PD patients had apparent dementia, as diagnosed using DSM-IV criteria [12]. All patients had mild-to-moderate motor disability, with stages between 1 and 3 on the 5-point Hoehn and Yahr scale [13]. All were fully ambulatory and receiving the optimal dosage of anti-parkinsonian medication prior to participation. Exclusion criteria were previous neurosurgery, presence of another disorder of the central or peripheral nervous system, for example, cerebral infarct or seizure disorder, and other major medical diseases, for example, coronary artery disease, alcoholism, or diabetes. All procedures were approved by the KMUH Human Research Ethics committee.

Twenty-seven age-matched normal controls (14 men, 13 women) were recruited from KMUH and the community. Control subjects were carefully screened to be free of any neurologic or psychiatric diseases. All participants were right-handed and literate.

Table 1 presents the demographic characteristics of both groups. No difference existed for gender ratio,
education years, and age between the two groups of participants ($\chi^2(1, n=54) = 0.68, p=0.41; t(52) < 1; t(52) < 1$, respectively).

**Procedure**
Informed verbal consent was obtained from each participant. The Stroop test was administered as part of a battery of neuropsychologic tests. The Comalli et al [14] version of the Stroop test was utilized in this study. There were three tasks in the Stroop test: word reading (WR); color patch naming (CN); and color word naming (CW). In each task, 100 stimuli were printed in a sheet. Each participant completed the three tasks in a fixed order: CN, WR and CW. Participants were required to name the ink color and ignore the word for the CW task. Total time to complete each task was measured. The number of errors that were not corrected and those that were corrected were counted.

**Data analysis**
The proportion score, $(CW−CN)/CN$, was not sufficiently sensitive to discriminate between patients and normal controls [15], as slow reading speed was not considered and could contribute to a slow naming of incongruent color words, irrespective of the Stroop interference [9]. Therefore, this study adopted Golden’s formula [16] to calculate interference scores, because it was based on an assertion that time to read a CW item was an additive function of the time to read a word plus the time to name a color, yielding the formula $(100/WR+100/CN)/(100/WR\times100/CN)$ for the predicted speed of reading a CW item (time-per-item). The interference score equaled the difference between predicted speed and actual speed.

Because participants typically corrected their errors immediately, corrected errors could result from the following facts: mistaken response to the item next to the target item, or a slip of tongue. It was reasonable to add corrected errors to the number of correct responses because corrections took time and contributed to an increased completion time. Therefore, the number of correct responses was calculated by the formula, $100−E+CE$, where $E$ was the number of errors without corrections and $CE$ was the number of corrected errors. Therefore, the interference score was calculated using this formula: $(100−E+CE)/CW−CW'$, where $CW' = [(100−E+CE)/WR \times (100−E+CE)/CN]/[(100−E+CE)/WR+(100−E+CE)/CN]$. A low score indicated increased interference.

**RESULTS**

**Speed performance**
Table 2 lists the completion time for the three tasks for PD patients and normal controls. The speed in completing the task was calculated as the completion time divided by the number of correct responses (Figure). Because the assumption of normality was not met, an arctangent transformation of the speed data was conducted. The transformed data were analyzed in a repeated measures analysis of variance with task (CN, WR and CW) as a within-subject factor and group (PD patients and controls) as a between-subject factor. The main effect of group was significant ($F(1, 51) = 15.15, p<0.001$). A contrast analysis showed that the PD group had a slower speed during the CN, WR, and CW tasks than the control group ($t(51) =2.86, p=0.006; t(51)=2.71, p=0.009; t(51) =3.69, p=0.001$, respectively). There was also a significant main effect of task ($F(2, 102) = 181.39, p<0.001$), indicating that the speed during the CW task was slower than that during the CN and WR tasks. The interaction between group and task was not significant ($F(2, 102) = 1.78, p=0.17$), indicating that the increasing trend of the function relating the speed to the WR, CN, and CW tasks was not different between PD patients and controls.

Based on subtraction logic, the mean time required to determine the ink color could be estimated as the speed difference between CN and WR tasks. The $t$ test
indicated that the time used to determine ink color was not significantly different between PD patients and controls, $t(51) < 1$.

**Interference score**

The interference score was calculated as described previously. The PD group had greater interference compared with the control group, $t(51) = -2.01, p < 0.05$. Second, the study also adopted another method of calculating an interference score by adapting the original formula for a proportion score [15] and replacing it with a time-per-item measurement. That is, the degree of interference was determined using the new formula: $(100 - E + CE)/CN$ minus $(100 - E + CE)/CW$, and then divided by $(100 - E + CE)/CN$. Similar to the previous result, the PD group had greater interference compared with that of the control group, $t(51) = -2.18, p < 0.05$.

**Accuracy performance**

Table 2 presents the uncorrected and corrected errors for the three tasks. Two accuracy measures were used: uncorrected errors and total errors (uncorrected and corrected errors). The PD group made a mean of 6.92 uncorrected and 11.61 total CW errors, and the control group made a mean of 1.81 uncorrected and 7.33 total CW errors. The Mann-Whitney U test showed no significant difference in median uncorrected or total errors between the two groups ($Z = -0.94, p = 0.35; Z = -0.78, p = 0.44$). Neither group made more than a mean of one uncorrected WR error. The Mann-Whitney U test showed no significant difference in median uncorrected or total CN errors between the two groups ($Z = -0.39, p = 0.70; Z = -0.32, p = 0.75$). These results together suggested that a slower speed to complete the three tasks did not result in increased accuracy.

**Other neuropsychologic tests**

Table 1 presents the mean scores on word list generation [17] and digit span [18]. A Bonferroni-adjusted $p$ value of 0.025 was set to compare these scores between the PD and control groups. Neither word

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**Table 2. Stroop test results of PD patients and controls**

<table>
<thead>
<tr>
<th>Test</th>
<th>PD patients ($n = 26$)</th>
<th>Controls ($n = 27$)</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color naming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion time</td>
<td>$100.96 \pm 32.60$</td>
<td>$79.85 \pm 20.46$</td>
<td>0.007†</td>
</tr>
<tr>
<td>Uncorrected errors</td>
<td>$1.15 \pm 1.57$</td>
<td>$1.41 \pm 2.04$</td>
<td>0.70‡</td>
</tr>
<tr>
<td>Corrected errors</td>
<td>$2.27 \pm 1.93$</td>
<td>$2.33 \pm 1.78$</td>
<td>0.85‡</td>
</tr>
<tr>
<td><strong>Word reading</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion time</td>
<td>$82.77 \pm 28.24$</td>
<td>$64.22 \pm 13.60$</td>
<td>0.005†</td>
</tr>
<tr>
<td>Uncorrected errors</td>
<td>$0.62 \pm 1.24$</td>
<td>$0.63 \pm 1.39$</td>
<td>0.95‡</td>
</tr>
<tr>
<td>Corrected errors</td>
<td>$1.27 \pm 1.22$</td>
<td>$1.00 \pm 1.07$</td>
<td>0.46‡</td>
</tr>
<tr>
<td><strong>Color-word naming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion time</td>
<td>$177.04 \pm 66.14$</td>
<td>$125.93 \pm 32.01$</td>
<td>0.001†</td>
</tr>
<tr>
<td>Uncorrected errors</td>
<td>$6.92 \pm 12.28$</td>
<td>$1.81 \pm 2.40$</td>
<td>0.35‡</td>
</tr>
<tr>
<td>Corrected errors</td>
<td>$4.69 \pm 3.76$</td>
<td>$5.52 \pm 4.73$</td>
<td>0.60‡</td>
</tr>
<tr>
<td><strong>Decision time for ink color</strong></td>
<td>$0.178 \pm 0.35$</td>
<td>$0.152 \pm 0.14$</td>
<td>0.72‡</td>
</tr>
<tr>
<td>Interference score</td>
<td>$0.035 \pm 0.14$</td>
<td>$0.141 \pm 0.23$</td>
<td>0.049†</td>
</tr>
</tbody>
</table>

*Data presented as mean ± standard deviation; †PD patients vs. controls by $t$ test; ‡PD patients vs. controls by Mann-Whitney U test.

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**Figure.** The completion speed (time per item; mean ± SEM) is a function of the word reading (WR), color patch naming (CN), and color-word naming (CW) tasks. The function has the same increasing trend for Parkinson’s disease (PD) patients and normal controls. *$p < 0.01$.
list generation nor digit span was significantly different between the two groups, indicating that verbal abilities and immediate memory in the PD group were still intact. This confirmed that the PD patients were not demented.

**DISCUSSION**

The major findings of this study were that the PD group showed greater Stroop interference and slower response times on the three tasks of the Stroop test, relative to the age-matched normal control group. The slowness of the CW task was mainly due to a deficit of response inhibition. Consistent with the study by Henik et al [4], PD patients had an impaired ability in inhibiting the naming of words. The difficulty in response inhibition was believed to be associated with executive dysfunction, such as a failure to maintain the task goal [5], or reduced resources of the supervisory attentional system [19] resulting from disruption of frontostriatial circuitry [3,20].

The slowness of the CN and WR tasks in the PD group was most likely due to motor response difficulties, rather than central processing deficits, because it was found that the decision time for ink color was not significantly different between the PD and control groups. Although this inference opposed the original hypothesis proposed on the basis of the findings of Revonsuo et al [10], it was supported by the following reasons. First, Revonsuo et al measured PD patient reaction times using a simple reaction time task (SRT) and choice reaction time task (CRT) separately, and then subtracted the SRT reaction time from that of the CRT. The difference in reaction times indicated the time required to execute a central cognitive process of perceptual discrimination. PD patients had slowed central cognitive processing; however, the CRT involved the stimulus-response matching process, which was different from the CN task of the Stroop test. Second, a comparable study by Hsieh [21] indicated that PD patients had difficulties in verbal initiation. Third, Bouquet et al [19] using the Hayling test showed that PD patients had difficulties in verbal initiation. Fourth, the PD group was not significantly different from the control group in the test scores of word list generation and digit span, with a medium effect size of 0.57 and 0.48, respectively. This insignificant result was not because of a small sample size, but indicated that PD patients might still have intact central processing of verbal information. Having said that, PD patients had an impaired ability of cognitive inhibition, this was not in conflict with the results of word list generation and digit span, because the latter did not particularly involve cognitive inhibition ability.

In short, the Stroop test results demonstrated that all three measures, including the interference scores and completion times on CN and WR tasks, successfully discriminated between patients and controls. The slowness of CN and WR in PD patients might be due to difficulties in verbal response initiation and/or execution. The increased interference in PD patients was due to their difficulties suppressing automatic reading of the colored words.

The results suggest that the cognitive and motor symptoms in PD can be differentiated based on performance on the Stroop test. These two distinct components in PD involve different pathological and neural mechanisms [22]. For instance, when administered dopamine agonists for eight months, PD patients with depression showed improved motor scores, but not cognitive scores, such as Stroop interference [23]. Following unilateral pallidotomy, PD patients show increased motility, but did not show improvements in Stroop test performance [24]. Similarly, subthalamic deep brain stimulation in PD patients had a good effect on motor problems, but an adverse effect on the Stroop color-word task [25,26]. A clinical implication of the results of this study is that PD patients’ performance on the Stroop test could be used to evaluate how dopamine agonist treatment or other medicines affect the cognitive and motor aspects of PD.

Depression has been associated with the slow response on the Stroop test in PD patients [27]. The possibility that the results of this study were due to depression could not be ruled out because the degree of depressive severity was not assessed. This was a limitation of this study.

In conclusion, the performance of PD patients on the Stroop test indicates that deficits in response initiation/execution and response suppression skills are two distinct characteristics of PD. The former can be revealed by the slow response times of the CN and WR task. The latter can be revealed by the slow response times on the CW task, specifically by the Stroop interference score. The dissociation of cognitive and motor components of Stroop test performance
may be implicated in evaluating long-term effect of any anti-parkinsonian medication on cognition and motion.

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巴金森症患者在 Stroop 測驗反應速度中的認知與動作成份

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本研究評估巴金森症患者在 Stroop 測驗的表現。二十七名巴金森症患者 (17 名男性和 10 名女性，平均年齡 63.3 ± 10.5 歲) 和二十七名年齡配對的正常控制組 (14 名男性和 13 名女性，平均年齡 63.5 ± 9.2 歲) 接受 Stroop 測驗中的色塊叫色、叫字，以及色字不相符的文字叫色作業。相較於正常控制組，巴金森症患者在三種作業的反應速度慢，而且 Stroop 干擾效果大，顯示巴金森症患者在反應抑制的缺損。進一步的分析顯示，巴金森症患者在色塊叫色作業的速度慢可能是因為動作緩慢的問題，而不是因為顏色區辨認知有問題。結論是，巴金森症患者在 Stroop 測驗的三種作業的表現反映出動作反應和認知抑制的能力受損。

關鍵詞：巴金森症，Stroop 干擾，Stroop 測驗
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