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Neuropsychologia 40 (2002) 1948–1955

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Task switching deficits associated with Parkinson's disease reflect depleted attentional resources

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Received 14 May 2001; received in revised form 24 April 2002; accepted 29 April 2002

Abstract

Using a Stroop task switching paradigm, Brown and Marsden [Brain 111 (1988) 323; Brain 114 (1991) 215] proposed that set shifting deficits in Parkinson's disease (PD) reflect limited attentional resources rather than deficits in internal control, as was previously supposed. In the present study, we tested this claim using a more recently developed Stroop task switching paradigm for which the internal control and attentional resources accounts made contrasting predictions. A PD group ($N = 30$) was compared with an age-matched control group ($N = 34$) on vocal response time (RT) for color naming and word reading in response to neutral and incongruent Stroop stimuli. Participants carried out four blocks of task repetition trials, and eight blocks of task switching trials. The results revealed that a deficit due to PD was absent for two conditions necessitating internal control, but was present in the condition which placed the highest demand on attentional resources. This selective deficit is congruent with Brown and Marsden's conclusions that depleted attentional resources, not an impairment in internal control per se, is the basis of the set shifting deficits associated with PD.

Keywords: Parkinson's disease; Task switching; Attentional resources; Stroop test; Executive functions

1. Introduction

Impaired set shifting has been consistently associated with Parkinson's disease (PD) [5,8,9,13,18,23,28,34,35] and has been attributed to a deficit using internal control of action [9,12,15,16,44]. For example, internal control is necessary when performing the Wisconsin Card Sorting Test: "in each trial there is nothing in the stimulus itself to indicate which of the three attributes is currently relevant. The subject must therefore focus attention on one attribute by means of some form of self-directed or 'internal' control" ([8, p. 325]).

In contrast to this view, it has been suggested that depletion of available attentional resources is the latent cause of the supposed internal control deficit in PD [8]. Using a task switching paradigm with incongruent Stroop stimuli,[1] Brown and Marsden induced an otherwise absent deficit in PD subjects on an externally cued task by depleting the available attentional resources, defined as the amount of mental effort invested in a given task [10]. The most straight-forward interpretation of their finding is that the reinforcing cortico-striate neural loops affected in PD [1,29,30,44] are involved in the allocation of attentional resources, and that this may manifest as a deficit in internal control under appropriately demanding experimental conditions.

Recent advances in task switching suggest that Brown and Marsden's experimental paradigm had methodological limitations. Most notably, their measure of task switching was based primarily on the response immediately following an *infrequent* switch (every 10 trials). Task switching using switches on alternate trials, e.g. [36] or on every trial, e.g. [2,4,21] have now been investigated in detail. Furthermore, as will be argued below, task switching using Stroop stimuli seems particularly valuable for comparing the internal control and attentional resources accounts of impairment in PD. This is because stimulus properties and task type can be independently manipulated, and the two theoretical accounts lead to different predictions regarding PD impairment induced by these manipulations.

With regard to stimulus properties, when participants are engaged in task switching, each encountered Stroop stimu-

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[1] Incongruent Stroop stimuli are color words printed such that the color of the ink is incongruous with the meaning of the word. Stroop color naming is presumed to be slow due to the interference caused by the relative dominance of processing the word dimension [25,42].

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PII: S0028-3932(02)00068-4

lus is ambiguous, such that it does not explicitly cue which task (word reading or color naming) to perform [40]. In this case, both tasks are elicited by the incongruent stimulus, and the participant must draw upon internal control to select the appropriate task [36]. In contrast, when neutral, unambiguous stimuli are processed (for example, naming the color of XXXX, or reading a word printed in black ink), the nature of the stimulus directly determines the now-relevant task, and the demand for internal control is greatly reduced. Thus, within the context of task switching, internal control is needed when responding to incongruent Stroop stimuli, but not when responding to neutral stimuli. When developing the task switching paradigm presented here, pilot work on young, unimpaired subjects [45] confirmed that when responding to incongruent Stroop stimuli, word reading and color naming are slowed relative to the neutral conditions, replicating previous work [2–4,46]. Therefore, if PD impairment when switching tasks is due to a deficit in utilizing internal control, the PD group should be more affected by stimulus properties than a control group; that is to say, they should be impaired on responses to incongruent relative to neutral stimuli, for both word reading and color naming.

This logic extends to task repetition. For incongruent color naming, both task switching and task repetition require internal control, because incongruent Stroop stimuli always elicit both the appropriate and inappropriate (and dominant) task. On the other hand, for word reading, if the stimuli are incongruent, task switching requires internal control, because the stimulus elicits both the appropriate and the inappropriate task; conversely, task repetition does not require internal control, because the stimulus elicits only the dominant, appropriate task.

In contrast to the effect of stimulus properties, for task type, the association with internal control is not direct. Task type is instead better conceptualized as linked to available attentional resources. For task repetition, color naming is slower, less automatic, and more difficult than word reading, and therefore demands more attentional resources (e.g. [39]). The demand on attentional resources becomes particularly pronounced when responding to incongruent Stroop stimuli [25,42].

The literature (e.g. [2]) and our pilot work [45] showed that within the context of task switching, mapping task type onto demand for attentional resources becomes more complex. For example, incongruent word reading is substantially slowed in a task switching environment, such that it can be more difficult than neutral color naming. However, it remains less demanding than incongruent-switching color naming, which was the most demanding condition. According to the depleted attentional resources account of PD deficits, this most demanding condition is most likely to expose impairment. This can be contrasted with the internal control account, which would predict that responses to all incongruent stimuli, for both word reading and color naming, would be significantly slowed in PD when switching tasks. Note that impairment on incongruent word reading, coupled with sparing on incongruent color naming, cannot be accounted for by either theoretical position.

Due to the general slowing associated with PD, between-group comparisons of RTs are valid only when taking into account the appropriate control conditions. Therefore, the aforementioned theoretical accounts were reformulated in terms of between-group comparisons of the *Stroop* and *reverse-Stroop* effects. The widely-studied Stroop effect is defined as slowed incongruent color naming relative to neutral color naming, and is substantial for both task switching and task repetition. The reverse-Stroop effect is the slowing of incongruent word reading relative to neutral word reading (i.e. color words printed in black ink), and is much more substantial within the context of task switching than in task repetition [2–4,38].

Using the Stroop and reverse-Stroop terminology, for *task switching*, the contrasting hypotheses can be stated as follows: if PD is associated with an impairment utilizing internal control, both the Stroop and the reverse-Stroop effects should be increased for the PD group relative to the control group. In contrast, if the PD deficit is due to depleted attentional resources, the most stringent prediction is that the Stroop effect within the context of task switching should be increased for the PD group relative to the control group. Importantly, if a group difference does not materialize in this most difficult condition, group differences in the less demanding conditions should also be absent. For *task repetition*, the internal control account would predict PD impairment only for the Stroop effect. The attentional resources account would also be compatible with PD impairment on the repeated Stroop effect, *but only if the switching-Stroop effect is also impaired*, as the latter is the most difficult condition.

The purpose of the present study was to contrast these two theoretical positions in their ability to account for PD impairments on a task switching paradigm. It was hypothesized that if PD is associated with an impairment utilizing internal control, both the Stroop and the reverse-Stroop effects should be increased for the PD group relative to the control group. In contrast, if the PD deficit is due to depleted attentional resources, the most stringent prediction is that the Stroop effect within the context of task switching should be increased for the PD group relative to the control group, and that group differences in the less demanding conditions should be absent.

2. Method

2.1. Participants

Subjects with PD, and a normal elderly (NE) control group were recruited from the community of Victoria, BC, by advertisement and referral. Each potential participant went through an initial screening interview, and was not tested

if he or she reported any of the following: stroke, transient ischemic attack, epilepsy, multiple sclerosis, Huntington's disease, Alzheimer's disease, encephalitis, meningitis, brain surgery, having been unconscious for more than 10 min due to head trauma, abnormal color vision, or poor vision that would affect viewing a computer screen. The original PD sample consisted of 33 people diagnosed as having idiopathic PD. The Mini-Mental Status Exam (MMSE [17], cutoff = 23) was used as a screen for dementia, and the Geriatric Depression Scale (GDS) as a screen for severe depression ([6], cutoff = 20). Two PD participants were excluded due to high GDS scores, and one PD participant was excluded due to a low MMSE score. This resulted in a final sample of 30 subjects with PD.

Participants in the final PD sample ($N = 30$) ranged in age from 37 to 84 years ($M = 69.31$, S.D. = 11.07) at the time of testing. The mean years of education was 14.60 (S.D. = 3.01). The duration of illness ranged from less than 1 to 18 years ($M = 5.77$, S.D. = 4.33). The sample consisted of 14 males and 16 females. All participants except one (duration of illness: 1 year, age: 58 years) had been prescribed medication to control their PD symptoms.

The NE group ($N = 34$) was matched to the PD sample for age ($M = 69.86$, S.D. = 9.99) and years of education ($M = 15.00$, S.D. = 2.23). The sample consisted of 12 males and 22 females. Control participants ranged in age from 46 to 85 years. None of these participants scored below the cutoff on the screening instruments. There were no significant differences between the two groups on age, education or gender, $t(62) = 0.21$, $P = 0.83$, $t(62) = 0.61$, $P = 0.55$, and $\chi^2(1) = 0.86$, $P = 0.36$, respectively. The consent of the participants in this study to the collection and publication of these results was obtained according to the declaration of Helsinki as revised in 1983, and was approved by the Ethics Committee of the University of Victoria.

3. Procedure and materials

3.1. Notation

In the present study, the following stimuli were employed: incongruent Stroop stimuli, for which color words were written such that the color of the ink was incongruent with the meaning of the word; neutral Stroop stimuli, which were color words printed in black ink for word reading, and a colored display of XXXX for color naming. The following notation will be used throughout the remainder of this manuscript:

1. Ci—color naming (C) in response to incongruent Stroop stimuli (i). This is an *incongruent color-naming response*;
2. Wi—word reading (W) in response to incongruent Stroop stimuli (i). This is an *incongruent word-reading response*;
3. Cn—color naming (C) in response to neutral Stroop stimuli (n). This is a *neutral color-naming response*;
4. Wn—word reading (W) in response to neutral Stroop stimuli (n). This is a *neutral word-reading response*.

As the stimuli were presented in pairs, combinations of these symbols will be used to represent these trial pairs. For example, the notation CiWi will refer to trial pairs characterized by color naming in position one, and word reading in position two, in response to sequentially presented incongruent Stroop stimuli. Similarly, the notation CnWn will refer to trials characterized by color naming then word reading in response to sequentially presented neutral Stroop stimuli.

4. Experimental procedure

Stroop stimuli (font uppercase Geneva 36 point) were presented using a Macintosh powerbook computer controlled by Psychlab software [11]. The colors and color words used for all stimuli were blue, yellow, red, green, and purple, and were presented on a white background. Participants in the present study were required to carry out uniform blocks of pure task repetition and pure task switching. For the latter, all possible combinations of task order and stimulus properties were presented in separate blocks.

4.1. Repetition trials

Testing began with a block of Wi or a block of Wn task repetition trials (35 trials each block). The order of the block presentation (Wi or Wn) was counterbalanced. This was followed by a block of Ci and a block of Cn task repetition trials (35 trials each block). The order of these blocks (Ci or Cn) was also counterbalanced. Participants were instructed to repeatedly name the color, or repeatedly read the word, depending upon the condition. After each response, a blank screen was presented, the experimenter manually typed any errors, and initiated advancement to the next trial by a key press.

4.2. Switching trials

For the switching conditions, stimuli were presented in sequential pairs of trials, and 35 uniform trial pairs formed one condition block. Prior to beginning the switching blocks, each participant was given the appropriate version of these instructions: "A box split into two halves will now appear on the screen. Name the color when the stimulus appears in the bottom half of the box, and read the word when it appears in the top half of the box. Please respond as quickly and as accurately as possible." The latter instructions are appropriate for subjects assigned to the color bottom/word top condition. In order to avoid the possible influence of location on switching performance, subjects were randomly assigned to the color bottom/word top and color top/word bottom

conditions. For subjects assigned to the color top/word bottom condition, the words "bottom" and "top" were interchanged in the instructions presented above. This task-to-location instruction remained valid for all eight switching blocks.

Task ordering within blocks was determined by the locations at which the stimuli were presented (i.e. top or bottom box). Thus, although the subjects were required to remember the task-to-location association for the duration of the experiment (and the same instructions were repeated at the beginning of each block), because the order of the tasks remained constant within blocks, subjects became familiar with the block-specific task order after the first few trial pairs. In addition to these changes in task order, stimulus properties also changed between the blocks (discussed below).

A switching-trial pair consisted of either (a) incongruent Stroop stimuli, where the participant responded either word-color (WiCi) or color-word (CiWi) and (b) neutral Stroop stimuli, where the participant responded either word-color (WnCn) or color-word (CnWn) or (c) one incongruent and one neutral stimulus, where the participant responded word-color (WnCi or WiCn) or color-word (CnWi or CiWn). Each participant received eight switching blocks (WiCi, CiWi, WiCn, WnCi, CnWi, CiWn, WnCn, CnWn) of 35 trial pairs per block (70 responses per block). That is to say, in each switching block, only one of the eight pair types was repeatedly presented. For example, for a participant in the color top/word bottom condition, for any of WiCi, WnCi, WiCn or WnCn blocks, the first stimulus would appear in the bottom box (for word reading), the second stimulus would appear in the top box (for color naming), and the screen would be blank while the experimenter typed errors and advanced to the next (identical) trial pair. This sequence would repeat 34 more times. Thus, differences between these four blocks would be based on stimulus type only, with task order remaining constant. Note that in this experimental arrangement, subjects switch tasks *on every trial* in these eight blocks. Within pairs, the response–stimulus interval (RSI) remained constant at 1000 ms. Between pairs, the RSI varied, determined by the speed with which the experimenter typed errors, and advanced to the next trial with a key press.

Fig. 1 displays the task design for a WiCi trial pair. A box divided into upper and lower halves preceded the arrival of the pair of trials by 15 ms. The first stimulus of the pair appeared in either the top or bottom half of the box, and disappeared from the screen when the vocal response time (RT) was recorded. After a response–stimulus interval of 1000 ms, during which time the box remained on the screen, the second stimulus of the pair appeared in the box section which was blank on the prior trial (i.e. there was a switch on every trial), and RT was recorded. After the completion of a trial pair, the experimenter manually typed any errors, and initiated advancement to the next trial pair (always another WiCi pair) with a key press. Use of the 1000 ms RSI was designed to maximize the probability that only residual switch costs were being measured [27,36].

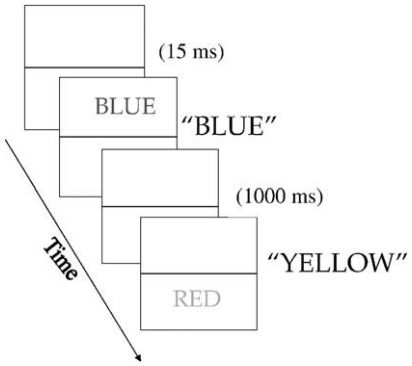

Fig. 1. Experimental design for a WiCi trial pair. A box divided into upper and lower halves preceded the arrival of the pair of trials by 15 ms. The subject in this example was assigned to the word top/color bottom instruction set. For the trial represented here, the first incongruent Stroop stimulus (BLUE printed in green ink) of the pair appeared in the top half of the box, and disappeared from the screen when the vocal response time was recorded. After a response–stimulus interval of 1000 ms, during which the box remained on the screen, the second incongruent Stroop stimulus of the pair (RED printed in yellow ink) appeared in the bottom half of the box, and RT was recorded. Therefore, the correct response sequence for the pair would be "BLUE", "YELLOW". After the completion of a trial pair, the experimenter manually typed any errors, and initiated advancement to the next trial with a key press. All blocks consisted of 35 uniform trial pairs (70 responses in total).

Presentation of the eight switching blocks was preceded by a practice block of 16 trial pairs, which included each combination of block type in random order. Experimental block presentation order was randomly determined for each subject. Following each block there was a break of approximately 1 min during which the experimenter prepared the computer software for presentation of the next block, and then repeated the original instructions. For all trials, individual stimuli were randomly selected (with replacement) from all word/ink combinations, excluding those which would result in congruent stimuli. Invalid trials were recorded as those where the voice-key picked up extraneous noise, or did not record a response. Any responses longer than 6500 ms, or shorter than 300 ms for all participants, but not coded as voice-key errors during testing, were coded as invalid trails *post-hoc* (<1% of RT trials), as were the responses to the first trial pair of each block.

5. Results

The word-reading and color-naming mean RTs and standard deviations for switching and repetition trials are displayed in Table 1. A full explanation of these data requires the estimation of a complex set of interactions, which are not reported here because they did not differ between the groups (these analyses are available elsewhere [45]). The analyses reported below involve averaging over the

Table 1
Reaction time (RT) means with standard deviations in parentheses

Block	Word reading		Color naming	
	PD	NE	PD	NE
CiWi	1145 (391)	947 (224)	1550 (511)	1245 (284)
WiCi	1122 (397)	999 (263)	1303 (386)	1147 (214)
CiWn	908 (280)	780 (141)	1413 (527)	1120 (195)
WnCi	929 (291)	787 (140)	1269 (337)	1060 (155)
CnWi	937 (375)	748 (166)	1050 (337)	897 (154)
WiCn	944 (433)	825 (183)	985 (245)	868 (125)
CnWn	810 (279)	643 (104)	944 (213)	829 (106)
WnCn	781 (207)	682 (104)	913 (178)	836 (116)
Wi	654 (86)	607 (90)	n.a.	n.a.
Wn	615 (75)	575 (91)	n.a.	n.a.
Ci	n.a.	n.a.	1150 (253)	1043 (141)
Cn	n.a.	n.a.	868 (159)	770 (109)

PD: Parkinson's disease group; NE: normal elderly group.

appropriate switching blocks. Note that for the switching conditions, both the first and the second stimulus in a pair was classified as switch trial. The RT of the first stimulus in a given pair was affected by a switch from the second stimulus in the preceding pair. Averaged over all conditions, only 1.0 errors per condition block were observed; therefore, results based on errors are not presented here.

The Stroop and reverse-Stroop RT differences (incongruent–neutral) were submitted to a $2 \times 2 \times 2$ mixed model analysis of variance (ANOVA) with task (word: reverse-Stroop versus color: Stroop) and switch (switching versus repetition) as within-subjects factors, and group (PD versus NE) as a between-subjects factor. This analysis resulted in a significant three-way interaction, $F(1, 62) = 9.29$, $P < 0.005$; however, inspection of specific contrasts were necessary to determine which theoretical account was most compatible with the results. This interaction can be interpreted as follows: for the reverse-Stroop effect, switch did not interact with group, $F(1, 62) = 0.22$, $P = 0.64$, and a significant main effect of switching was present (repetition $M = 35$ ms; switching $M = 168$ ms), $F(1, 62) = 58.65$, $P < 0.001$. For the Stroop effect, the repeated-Stroop effect ($M = 278$ ms) did not differ significantly between the groups, $t(43.96) = 0.31$, $P = 0.76$, but the switching-Stroop effect was greater for the PD group ($M = 410$ ms) than for the NE group ($M = 282$ ms), $t(39.88) = 2.61$, $P = 0.01$. Accordingly, the interaction between switch and group was significant, $F(1, 62) = 7.53$, $P < 0.01$, such that the Stroop effect was increased when switching for the PD group, but not for the NE group (see Fig. 2).

6. Discussion

In the present study, when responding to Stroop stimuli (relative to the appropriate neutral control conditions), people with PD were (a) impaired on incongruent color naming when switching tasks, (b) unimpaired on incongruent color

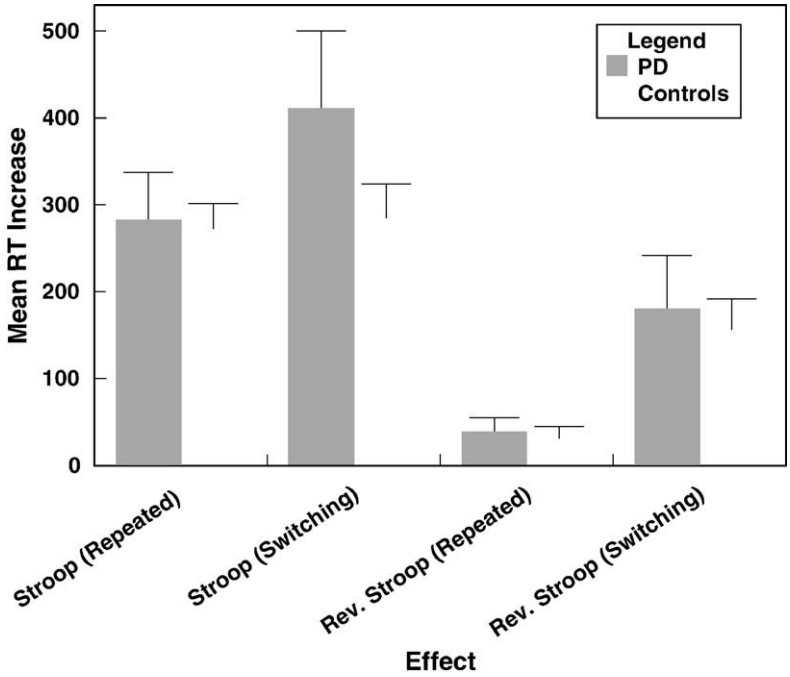

Fig. 2. Mean RT increase associated with each effect, plotted as a function of group (Parkinson's (PD) vs. age-matched controls (Controls); 95% confidence intervals). The Stroop effect is the incongruent color-naming RT increase over neutral color-naming RT. Rev. Stroop is notation for the reverse-Stroop effect, which is the incongruent word-reading RT increase over neutral word-reading RT. The Stroop and reverse-Stroop effects were measured in both the switching and repeated conditions.

naming when repeating tasks, (c) unimpaired on incongruent word reading when switching tasks, and (d) unimpaired on incongruent word reading when repeating tasks. This set of results is not compatible with the assertion that impaired use of internal control is the basis of a deficit in PD, because impairment was absent for incongruent-switching word reading, and incongruent-repeated color naming, conditions which demand the use of internal control. It is, however, compatible with depleted attentional resources account, as the PD deficit was present in the most resource demanding condition; namely, incongruent color naming when switching tasks.

The affected structures in PD are those in a reinforcing cortico-striate neural loop originating in widespread areas of the cortex (frontal, parietal and temporal areas) through the basal ganglia (caudate, putamen, globus pallidus and substantia nigra), to various thalamus nuclei, and fed back to widespread cortical areas through the prefrontal cortex [1,29,30,44]. Put simply, through this loop the basal ganglia can influence high-level cognitive processes via the thalamus [7]. These results are compatible with an account holding that efficient allocation of attentional resources is dependent upon the integrity of this cortico-striate loop. In support of this position, Taylor and Saint-Cyr [43] suggested that the basal ganglia may automatically reduce the activation of irrelevant and competing stimulus-response mappings, reducing the burden on the prefrontal cortex, and that damage to these structures may stretch the available attentional resources beyond their limit under certain conditions.

An alternative explanation which is also compatible with this set of results is that a deficit when switching to the non-dominant task is present in PD. In congruence with this account, we have observed that incongruent-switching color-naming elicits more widespread activation in the dorsolateral prefrontal cortex (DLPFC) than incongruent-repeated color naming, incongruent-switching word reading, and incongruent-repeated word-reading conditions [38]. This finding may be important given that the DLPFC has rich interconnections to the subcortical brain structures affected by PD [29,30,44]. Although task switching deficits have been linked to frontal lobe damage [37], and aging [22,26], these studies employed apparently equidominant tasks, so that an increased reliance on the DLPFC for switching to the non-dominant task has not been directly tested. Thus, more evidence would be necessary to support this alternate account while ruling out the depletion of attentional resources account.

Finally, it should be noted that a generalized slowing account of PD impairment does not fit well with the overall pattern of results. Consider the color-naming RTs: in addition to slow responses in the critical incongruent-switching condition, the PD group displayed slowing in all other conditions (i.e. neutral switching, and all task repetition conditions); however, in these other conditions, the slowing was a constant value, independent of stimulus properties and task difficulty. Correspondingly, translation of the RT differences to ratios did not alter the set of results reported here.

The absence of impairment for the traditional Stroop paradigm in the present work (i.e. incongruent-repeated color naming), appears to contradict the conclusions of comprehensive reviews of neuropsychological test performance in PD [14,32]. However, the validity of the conclusions reached in these review articles must be called into question. Serious interpretational difficulties are present, such as (a) absence of the incongruent condition [44], (b) absence of the neutral condition [8], (c) very weak significance for group mean differences [20] (young sample), (d) a failure to separate group differences in Stroop interference from group differences in color naming [20,24,31], (e) failure to screen for dementia [24], and (f) study of a sample with general impairments [20] (young sample). Impairment due to PD on the Stroop test is consistently absent when (a) an appropriate control condition is covaried out of incongruent color naming and (b) the control group is matched for age and level of intellectual functioning [12,20] (elderly sample [33,41]).

The possibility that task demands on attentional resources play an important role in determining PD performance may explain the between-study disagreements in recent reports of task switching deficits in PD. For example, one study reported no switching deficit for PD [37], whereas a second reported a PD deficit [19]. This discrepancy may be attributable to methodological differences between studies which map onto differential demands upon attentional resources. For example, the study which did not find a PD deficit used a predictable task order, whereas the study reporting a PD deficit used a random presentation order—the latter may place more demands upon attentional resources.

The results reported here support the assertion that deficits in the use of internal control are manifestations of reduced attentional resources (and/or inefficient allocation of attentional resources) in PD. An improved understanding of the interaction between demands upon attentional resources and PD performance deficits would seem important factors to consider when designing and interpreting studies investigating cognitive deficits in PD, and when assessing inconsistencies in the existing literature. Future work may focus on direct manipulations of attentional resources while switching tasks in order to more comprehensively test the plausibility of the depleted attentional resources account of PD performance deficits.

Acknowledgements

The authors thank Alex Moll for assistance with patient recruitment, Christine Schwartz for assistance with data preparation, and Peter Graf, Mike Hubner, Claudia Jacova, Beat Meier, Steffen Moritz, and Christian Ruff for providing suggestions on early versions of this manuscript.

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