Comparison of the Basal Ganglia and Cerebellum in Shifting Attention

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Abstract

■ The basal ganglia and cerebellum have traditionally been associated with motor performance. Recently, there has been considerable interest regarding the contributions of these subcortical structures to aspects of cognition. In particular, both the basal ganglia and cerebellum have been hypothesized to be involved in the control of attentional set. To date, no neuropsychological studies have directly compared the effects of basal ganglia and cerebellar dysfunction on the same attention shifting tasks. To this end, we employed an alternating attention task that has been used to demonstrate putative attentional control deficits in children with cerebellar pathology, either related to autism or neurological insult. When adult patients with either Parkinson's disease or cerebellar lesions were tested on this task, a similar pattern of deficits was observed for both groups. However, when the motor demands were reduced, cerebellar patients showed a significant improvement on the alternating attention task, whereas the Parkinson patients continued to exhibit an impairment. This dissociation suggests that attentional deficits reported previously as being due to cerebellar dysfunction may be, at least in part, secondary to problems related to coordinating successive responses. In contrast, attention-shifting deficits associated with basal ganglia impairment cannot be explained by recourse to the motor demands of the task. ■

INTRODUCTION

Human behavior is highly flexible. We readily switch from one task to another, either in response to the availability of new information or as a function of fluctuations in the momentary goals that guide our actions. The construct of executive functions has been used to encompass the set of mental processes that underlie such flexibility, allowing us to vary our attentional set in order to plan and coordinate goal-oriented behavior, as well as respond to novel situations (Norman & Shallice, 1986). Prefrontal cortex has traditionally been assumed to play a central role in these complex cognitive processes, coordinating the selection and planning of action at an abstract level and then translating this plan into a specific movement through its interactions with cortical and subcortical components of the motor system (Duncan, 1995; Luria, 1966). However, recent studies have suggested that the functional domain of the basal ganglia and cerebellum is not restricted to the implementation of motor commands. Rather, these structures have been hypothesized to contribute in a substantive manner to cognitive processes associated with executive control. Evidence of a network for executive control that encompasses prefrontal cortex, the basal ganglia, and cerebellum comes from a diverse set of anatomical (Middleton & Strick, 1994), neurophysiological (Houk, 1997), neuroimaging (Allen, Buxton, Wong, & Courchesne, 1997; Kim, Ugurbil, & Strick, 1994), and neuropsychological studies (Daum & Ackermann, 1997; Gotham, Brown, & Marsden, 1988).

Characterizing the functional contribution of these systems to executive processes remains a challenging problem. Separate lines of investigation implicate both the basal ganglia and cerebellum in the control of attentional set. Neuropsychological studies have found that both patients with Parkinson's disease (Owen et al., 1993; Taylor, Saint-Cyr, & Lang, 1986) and patients with cerebellar pathology have difficulty in switching attentional set (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992). For both subcortical structures, researchers have proposed a cognitive deficit analogous to the prominent motor symptoms associated with damage to either the basal ganglia or cerebellum. Parallel to the motor symptom of akinesia, Parkinson patients have been hypothesized to have difficulty instantiating a new attentional set (Hayes, Davidson, Keele, & Rafal, 1998; Rogers et al., 1998). Hayes et al. (1998) found that Parkinson patients, in addition to exhibiting deficits of a motor sequencing task, were also impaired in shifting attentional set between two perceptual dimensions (e.g., color and shape). Others have found these patients to be impaired on the Wisconsin Card Sorting Test (Eslinger & Grattan, 1993; Gotham et al., 1988) and at

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discrimination learning (Owen et al., 1993; Downes et al., 1989)– both tasks that require alternating between stimulus dimensions in order to make correct responses.

The difficulty for patients with cerebellar damage on attention shifting tasks has been hypothesized to reflect a problem in rapidly coordinating mental activity; similar to the way this structure is essential for the coordination of rapid movements (Courchesne & Allen, 1997). Courchesne et al. have provided evidence that children with cerebellar pathology, related to autism or neurological insult, are impaired in their ability to rapidly alternate attention between different sensory channels (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992), as well as between different dimensions within a single sensory channel (Akshoomoff & Courchesne, 1994). Moreover, event-related potentials obtained during these experiments indicate that the participants have missed the targets rather than simply failed to respond.

Different hypotheses have been proposed to account for how the cerebellum and basal ganglia contribute to the control of attentional set, each developed to provide a link between the functional role of these structures in cognition and motor control. For the cerebellum, the functional hypothesis has centered on a role in rapidly coordinating shifts of attention. For the basal ganglia, the functional hypothesis has involved the idea of overcoming the inertia associated with the current set to engage a new set. While the differences between these two hypotheses are likely to be subtle, it is instructive that no experiments have been conducted to directly compare the effects of pathology to these two structures on the same set of tasks. Moreover, most of the work on the role of the cerebellum in attention shifting has been conducted with young participants, whereas the basal ganglia studies have always involved elderly participants. To this end, we tested adult patients with either lesions to the cerebellum or basal ganglia on two versions of the same set of attention-shifting tasks. In this manner, we sought to provide direct evidence of the functional similarities and differences in executive control processes between the cerebellum and basal ganglia.

EXPERIMENT 1

We used a task introduced by Courchesne et al. in their studies on the role of the cerebellum in attention shifting (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992). Subjects were presented with a continuous series of stimuli forming two streams, one visual and one auditory. Within each stream, one stimulus value was designated the target and a second stimulus value was designated the distractor. Each distractor was presented twice as often as the targets. The stimuli were presented one at a time in a pseudorandom sequence with the interstimulus interval ranging from 450 to 1450 msec. On the alternating attention task, subjects were instructed to switch between the two dimensions, responding to a target on one dimension, then a target on the other dimension, and so forth (Figure 1a). For a control condition, the subjects performed a focused attention task in which they responded to targets on only a single dimension (Figure 1b–c). The number of targets (and, correspondingly, the number of responses) was equated for the alternating and focused conditions. Thus, the difference in performance between the two conditions is assumed to reflect the cost associated with switching attentional set.

In a number of studies, Courchesne et al. (1992, 1994) have found that autistic individuals and children with cerebellar lesions fail to respond to targets on the alternating attention condition when the intertarget interval (ITI) is relatively short (< 2.5 sec). Two comparisons have led them to conclude that this result provides evidence of an impairment in performing rapid shifts of attention. First, a similar deficit is not apparent in the focused attention condition, arguing against a generalized problem on conditions requiring two successive responses. Second, the patient groups perform comparable to control participants on the alternating attention condition when the interval between successive targets is longer than 2.5 sec (although the lack of a deficit here must be interpreted cautiously since many of the participants' performance is near ceiling). Thus, the patient groups appear to recognize that they must shift their attentional set after detecting a target, but are unable to do so in a rapid, coordinated manner.

In the first experiment, we tested a group of adult patients with cerebellar lesions on the same tasks to assess the generalizability of the findings of Courchesne et al. In addition, we also tested patients with Parkinson's disease, using this group as a model for studying basal ganglia pathology. While various studies have proposed a deficit in shifting attentional set related to Parkinson's disease, the tasks used in those studies are quite different than the attention shifting tasks of Courchesne. Thus, comparisons across studies are limited.

Results and Discussion

The percentage of hits obtained by patients in the alternating attention condition was compared to that of the control subjects by using a repeated-measures ANOVA with group as the between-subjects factor and time between successive targets (ITI) as the within-subjects factor. The interaction of Group × ITI was not significant in comparing the controls and cerebellars [$F(1,14) = 0.5, p > .1$] nor the controls and Parkinson patients [$F(1,15) = 1.29, p > .1$]. Instead, main effects of ITI were obtained for both comparisons [cerebellars and controls: $F(1,14) = 29.14, p < .01$; Parkinson and controls: $F(1,15) = 49.76, p < .01$]. Both patient groups performed significantly worse in the alternating attention condition at the short ITI than at the long ITI.

The lack of significant Group × ITI interactions in the alternating attention condition may be due to the higher level of performance overall by the patients in comparison to that observed by Courchesne et al. (1992, 1994) in their studies with young autistic and cerebellar subjects. The potential for improvement between the two intervals was thus attenuated. Although not significant, both patient groups tended to show greater improvements in performance as ITI lengthened compared to controls (Figure 2a). Consistent with the Courchesne et al. studies, there were no significant Group × ITI interactions in the focused attention conditions in comparing the controls to cerebellar patients [$F(1,14) = 0.03$, $p > .1$] or controls to Parkinson patients [$F(1,15) = 2.53$, $p > .1$; Figure 2b].

Given the potential problems imposed by the high levels of performance at the long ITI in the alternating attention condition, we supplemented the between-groups analyses described above by analyzing each group separately to determine how ITI affected performance in each attention condition. Repeated-measures ANOVAs were conducted for each group with ITI (short vs. long) and attention (alternating vs. focused) as within-subjects factors. Control subjects displayed a main effect of ITI [$F(1,7) = 19.6$, $p < .01$], a marginal effect of attention [$F(1,7) = 4.38$, $p = .075$], and no interaction

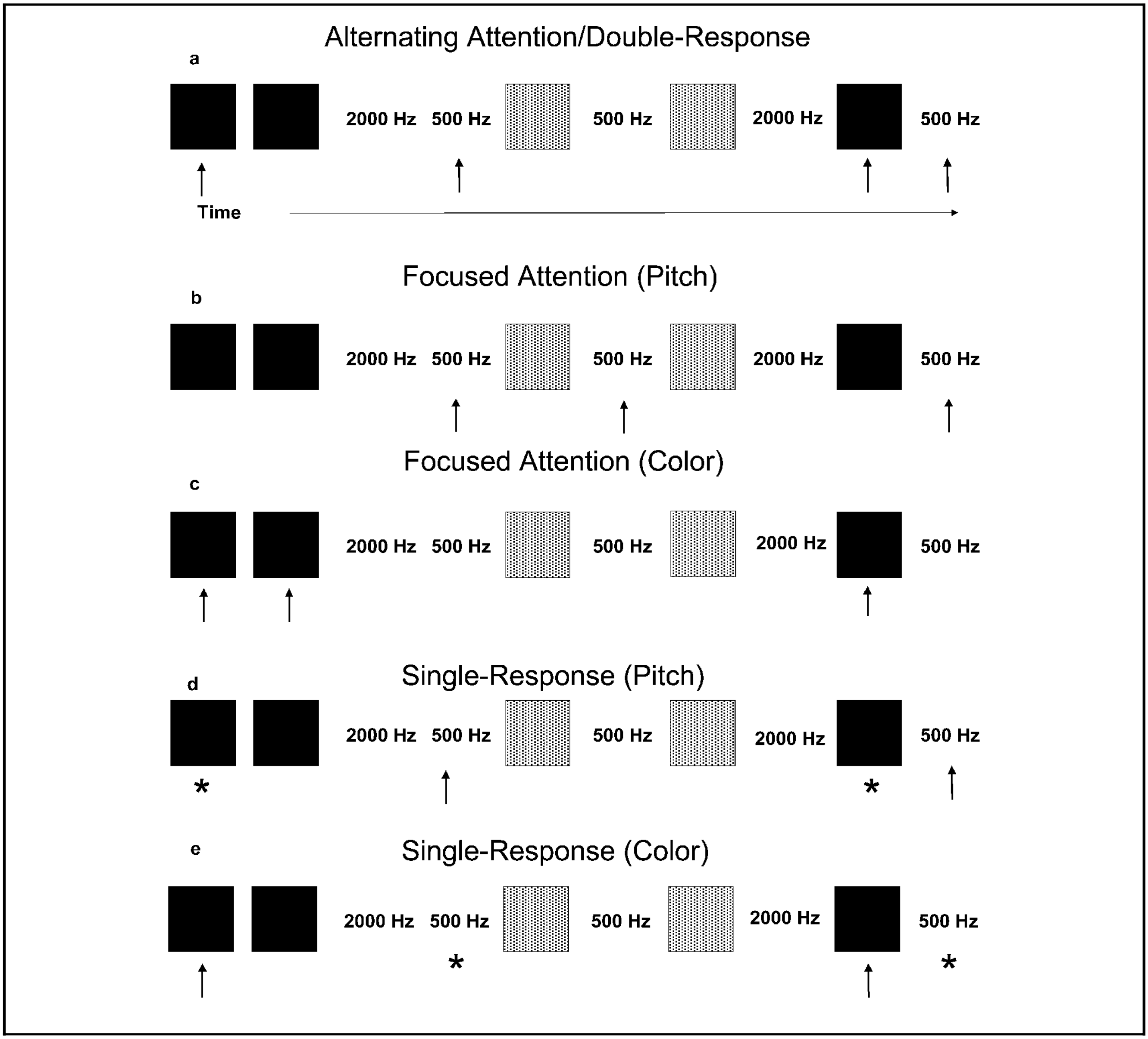

Figure 1. Sample stimulus sequences and responses for each condition. Red squares and low-pitch tones are targets to be detected and the distractors are blue squares and high-pitch tones. Arrows indicate than an attention shift and/or key press are required. Asterisks indicate that only an attention shift is required. Conditions are: (a) alternating attention (Experiment 1)/double-response (Experiment 2); (b) focused attention–pitch; (c) focused attention– color; (d) single-response– pitch; (e) single-response– color.

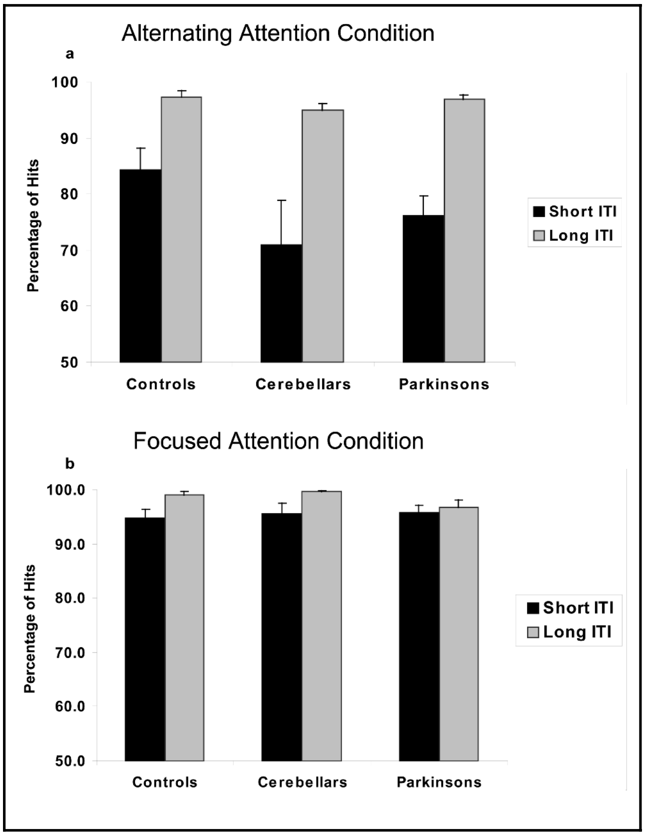

Figure 2. Percentage hit rate of controls and patients at the short and long ITI in the (a) alternating and (b) focused attention (collapsed across pitch and color) conditions.

effect [$F(1,7) = 1.69$, $p > .1$]. A main effect of ITI was also obtained for cerebellar subjects [$F(1,7) = 21.33$, $p < .01$], but there was also a significant main effect of attention as well [$F(1,7) = 16.38$, $p < .01$]. The cerebellar patients performed more poorly in the alternating (83%) than in the focused attention (98%) conditions. Performance did not differ between cerebellars with focal lesions ($n = 5$) or atrophy ($n = 3$) in either the alternating (82% vs. 85%) or focused (97% vs. 98%) attention conditions ($ps > .1$). The interaction effect of ITI × Attention approached significance [$F(1,7) = 4.4$, $p = .074$]. In summary, the current results are in accord with the findings of Courchesne et al. (1992, 1994). Patients with lesions of the cerebellum have difficulty on the alternating attention condition, especially when the interval between successive targets is relatively short.

However, the analyses of the results for the Parkinson patients indicate that the observed deficits on this task are not limited to patients with cerebellar pathology. Significant effects of ITI [$F(1,8) = 45.6$, $p < .01$], attention [$F(1,8) = 11.76$, $p < .01$], as well as the interaction of ITI × Attention [$F(1,8) = 14.94$, $p < .01$] were obtained for the Parkinson group. Simple comparisons were conducted to explore the significant interaction effect displayed by Parkinson patients. Paired-sample t tests indicated that Parkinson patients performed less accurately at the short ITI than at the long ITI in the alternating attention condition [$t(1, 8) = 5.95$, $p < .01$] but performed equally well at both ITIs in the focused attention condition [$t(1, 8) = -.641$, $p > .1$]. In addition, performance was less accurate at the short ITI in the alternating attention condition than in the focused attention condition [$t(1, 8) = 4.46$, $p < .01$]. Parkinson patients who had undergone surgical intervention ($n = 2$) showed a comparable difference in performance (22%) between the two attention conditions at the short ITI compared to those who had not had surgery (19%; $n = 7$). None of the results changed by excluding the two surgery patients from statistical analyses.

Thus, the overall pattern of results for the Parkinson patients is similar to that obtained for the cerebellar group. For both groups, accuracy is worse for the short ITI bin compared to the long ITI bin in the alternating attention condition . Moreover, the patients performed more poorly when having to alternate attention compared to the focused attention conditions in the short ITI condition. The only hint of a dissociation between the two groups is that the interaction is only significant for the Parkinson patients, suggesting that these patients are specifically impaired when having to shift attention rapidly. In contrast, the lack of an interaction would suggest that the cerebellar group is impaired at all intervals on the alternating attention condition. However, as can be seen in Figure 2, the cerebellar group's performance tended to improve as the time between successive targets (and responses) increased.

In the alternating attention condition, a failure to inhibit responses to targets in the unattended stream may result in a high false alarm rate (Figure 3). To determine whether patients were more prone to these types of errors, the percentage of false alarms was also subjected to a Group × ITI repeated-measures ANOVA. The results indicate that cerebellar subjects overall made more false alarms (4.9%) than controls (2.1%) regardless of ITI [Group: $F(1,14) = 6.07$, $p < .05$; ITI: $F(1,14) = 0.07$, $p > .1$; Group × ITI: $F(1,14) = 0.21$, $p > .1$). The Parkinson patients, on the other hand, made more false

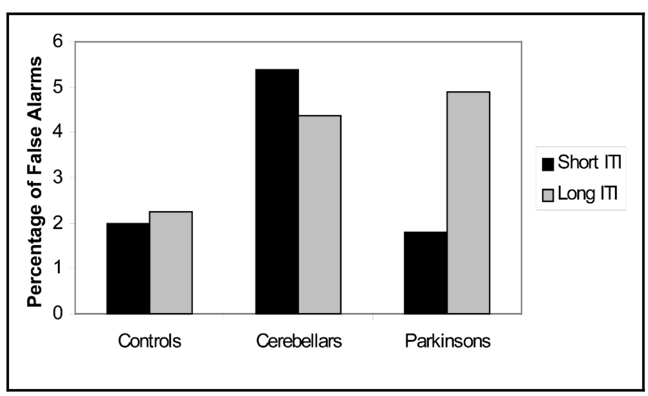

Figure 3. Percentage of false alarms in the alternating attention condition.

alarms than controls only when the ITI was long [$F(1,15) = 5.26, p < .05$]. A high false alarm rate when the ITI is long may indicate that these patients had some difficulty in maintaining set for an extended period.

The current results extend the work of Courchesne et al. in demonstrating that adult patients with acquired cerebellar lesions have difficulty on tasks that require rapid shifts of selective attention between two perceptual streams. The relatively selective deficit on the alternating attention condition at short ITIs is similar to the results previously obtained in studies with autistic individuals or children with acquired cerebellar disorders. The conclusions concerning the role of the cerebellum in attention shifting, however, are qualified by the fact that we obtained similar results for the Parkinson patients. To the pessimist, the similar performance for the two groups would indicate that this task is not sufficiently analytic to specify the particular deficits associated with cerebellar and basal ganglia disorders. On the other hand, the complex operations required for executive operations such as maintaining and modifying attentional set will surely involve a network of neural structures. The current results are consistent with the hypothesis that both the cerebellum and basal ganglia are part of such a network.

The inclusion of the focused attention conditions would appear to rule out an account of the results based on the motor problems of our patients. Given the structure of the tasks, the number and timing of the responses are similar in the alternating and focused attention conditions. However, it is still important to consider the possible consequences of a motor control deficit on these tasks, an issue that has generally been ignored in the recent literature on cognitive functions of the cerebellum and basal ganglia. This issue can best be understood in terms of a general resource model (Kahneman, 1973). The alternating condition is obviously much more difficult, not only for the patients, but also for the control participants. Thus, one would expect this condition to require additional (specific and/or general) resources. However, the ability to recruit these resources would be limited if they were required for other aspects of performance. For our patient groups, resources might be especially limited when successive responses have to be emitted in rapid succession. Certainly, this is a demanding situation for patients with cerebellar dysfunction, a condition in which the motor impairment is most pronounced at the end of a response (Hore, Wild, & Diener, 1991). The effort required to terminate a response successfully may impact the ability of these patients to prepare for the next goal.

In essence, the preceding paragraph raises a concern that the problems manifested by the patient groups on the alternating task at the short ITI might reflect an interaction of the higher attentional load in this condition coupled with the need to monitor ongoing responses. That is, the apparent attention-shifting deficit might be secondary to the motor demands involved in preparing, controlling, and terminating responses when cognitive demands are high. Relative to the controls, the patients may need to devote more attentional resources to controlling their responses, and this would detract from their ability to switch attention in the demanding alternating attention condition. With a sufficiently long ITI, the attentional shift would occur well after the previous response has been concluded. With a short ITI, these processes would overlap. The focused attention conditions may not be sensitive to these resource issues given the near ceiling performance of the participants on this task.

EXPERIMENT 2

To examine the resource issue, we developed a modified version of the alternating attention task that reduced the motor requirements. The participants were tested on two versions of the alternating attention task. One version, the double-response condition, was identical to that used in Experiment 1 (Figure 1a). Subjects alternated between the two modalities, responding to each target on the attended modality. In the other version, the single-response condition, the attentional requirements were the same, but overt responses were only required to targets on one modality (Figure 1d–e). Targets on the other dimension served as cues to switch attention, but did not require an overt response. In this manner, the number of attention shifts was equated for the two versions of the alternating attention task, but the subjects never had to make two responses in rapid succession in the single response condition.

Results and Discussion

As in Experiment 1, each patient groups' hit rate in the double-response/alternating-attention condition was compared to that of the control subjects by using a repeated-measures ANOVA with group as the between-subjects factor and ITI as the within-subjects factor. Again, these interactions were not significant ($ps > .1$), although cerebellar and Parkinson patients' performance tended to improve more than controls as ITI lengthened (Figure 4a and b). The percentage of false alarms was also examined for this condition (Figure 5) and no significant group, ITI, or interaction effects were found ($ps > .1$).

Of primary interest to this study is whether the performance of the patients improved when the motor demands were reduced in the single-response condition. To assess this, accuracy scores of the patients at the short ITI were subjected to a repeated-measures ANOVA with group as the between-subjects factor and the level of motor demands (double vs. single response) as the within-subjects factor. This analysis showed that cerebellar patients improved significantly more than Parkinson patients [$F(1,17) = 4.69$, $p < .05$] in the single-response condition. The performance of the Parkinson group was minimal on the critical trials involving a short ITI: Overall, this group showed less than a 1% improvement compared to the double-response condition. In contrast, the mean improvement for the cerebellar group is 10%. Paired-sample t tests showed that the cerebellar patients' accuracy improved from the double- to single-response condition [$t(1, 9) = -3.66$, $p < .01$] while the performance of the Parkinson patients did not improve [$t(1, 8) = -0.35$, $p > .1$].

There were no consistent differences in improvement (ps $> .1$) between the cerebellar patients with focal lesions and those with atrophy. The mean improvement for the focal group was 8% and that for the atrophy group was 13%. Various comparisons of subpopulations of the Parkinson patients indicated no consistent differences. The patients with prominent bradykinesia ($n = 4$) showed a 3% improvement in the single-response condition; patients with dyskinesia ($n = 2$) were 5% less accurate in this condition. When the patients were divided on the basis of whether or not they had undergone surgical intervention, the means for the two groups were comparable, both exhibiting a less than 1% improvement. As before, all statistical analyses were redone without the surgery patients. The results did not change for any test except that the interaction of Group (Parkinson/cerebellar) × Response (double/single) became only marginally significant [$F(1,14) = 4.12$, $p = .062$].

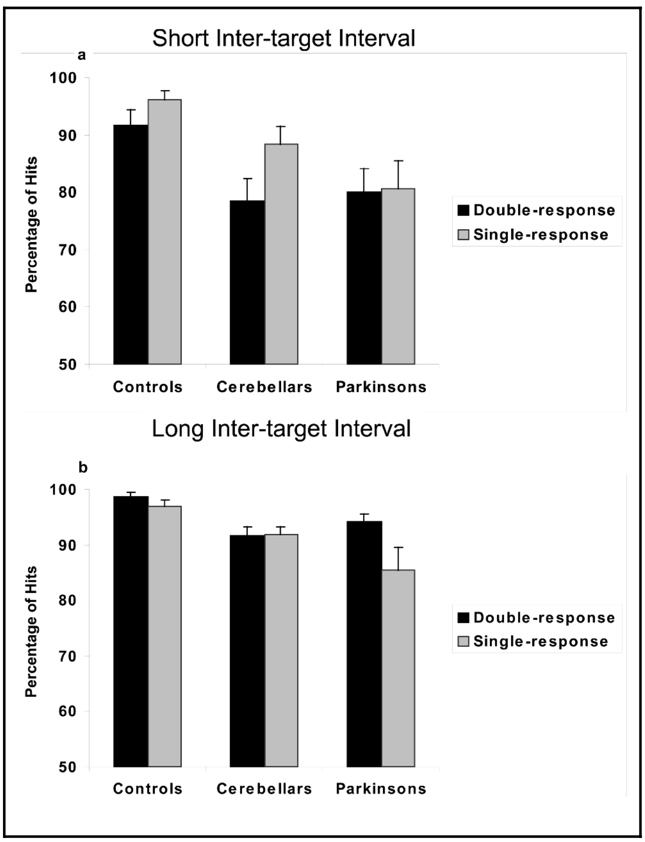

Figure 4. Percentage hit rate of controls and patients in the double-response and single-response (collapsed across pitch and color) conditions at the (a) short ITI and (b) long ITI.

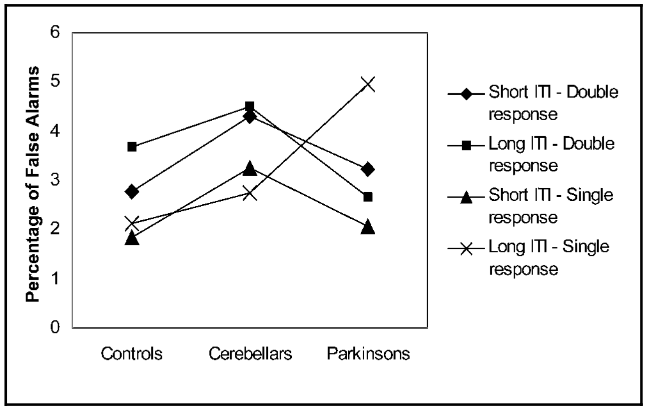

Figure 5. Percentage of false alarms in the double- and single-response conditions at short and long ITIs.

Figure 6 plots the difference for each patient in the two versions of the alternating attention task for targets occurring at short ITIs. As can be seen, a large proportion of the patients with cerebellar lesions improve in the single-response version. The fact that the cerebellar patients were able to make successive speeded responses on the focused attention conditions of Experiment 1 indicates that they do not always have problems on tasks requiring rapid successive responses. Rather, the results indicate an interaction between the motor and cognitive demands of the task, with the attention-shifting deficit only occurring when they have to make rapid successive responses in a cognitively demanding task. The difference scores for the Parkinson patients are

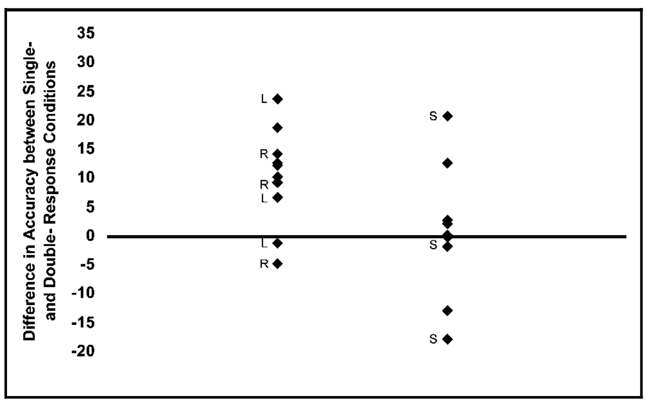

Figure 6. Difference in performance between the single- and double-response conditions for 10 cerebellar and 9 Parkinson patients. The accuracy score in the double-response condition was subtracted from that obtained in the single-response condition for targets at short intertarget intervals. Positive scores indicate improvement when the motor demands are reduced. The letters next to each point indicated whether cerebellar patients had left (L) or right (R) focal lesions while atrophic patients were unmarked. Parkinson patients who had undergone a pallid/thalidotomy (S) were differentiated from those who had not undergone surgical intervention.

much more variable, spread equally among those showing an improvement and those showing a decrement. This result indicates that their ability to execute rapid shifts of attention between the two dimensions is not a function of the motor demands of the task.

It is important to note that the cerebellar patients perform more poorly than the controls in all conditions. This difference is underscored by the fact that a three-way ANOVA of Group (cerebellar/control) × ITI (short/long) × Condition (single response/double response) revealed a main effect of Group [$F(1,17) = 12.77$, $p < .01$]. If the ANOVA is restricted to the single-response condition, the main effect of Group remains significant [$F(1,17) = 7.15$, $p < .05$]. Thus, the patients with cerebellar lesions continue to exhibit an impairment relative to the control group on this task. However, their deficit is not specific to the short ITI condition. Thus, these results challenge the notion that the problem for these patients is related to an inability to rapidly shift attention, at least for tasks that do not include the added burden of making rapid successive responses.

Unexpectedly, the Parkinson patients' accuracy decreased in the single-response condition relative to the double-response condition at the long ITI. Moreover, false alarms increased in this condition (see Figure 5), a finding consistent with that observed in Experiment 1 in which Parkinson patients made more false alarms on the alternating condition in the long ITI condition. These results suggest that the Parkinson patients may have difficulty maintaining attentional set over an extended period. Both the misses and false alarms here indicate that the patients are attending to the wrong dimension. (Note that these errors are only recorded after a correct response has been made.)

The fact that this problem became more pronounced in the single-response condition may reflect the added cost of inhibiting responses to stimuli that had previously been designated targets. To test this hypothesis, we compared the performance of the three subjects in each group who had been tested in the double-response condition first to those who had been given one of the single-response conditions first. As can be seen in Figure 7, the decrement in performance at the long ITI is especially pronounced for the Parkinson patients who began with the double-response condition. For the Parkinson patients who began with the single-response condition, the decrement at the long ITI was similar to that observed for the control participants. Given the small number of participants tested under the different orders, no statistical analyses were performed. To further explore order effects, five new Parkinson patients were tested on the protocol of Experiment 2, but always tested on the two single-response conditions prior to the double-response condition. For these patients, the decrement at the long ITI was only 6%, similar to the pattern shown in the top of Figure 7.

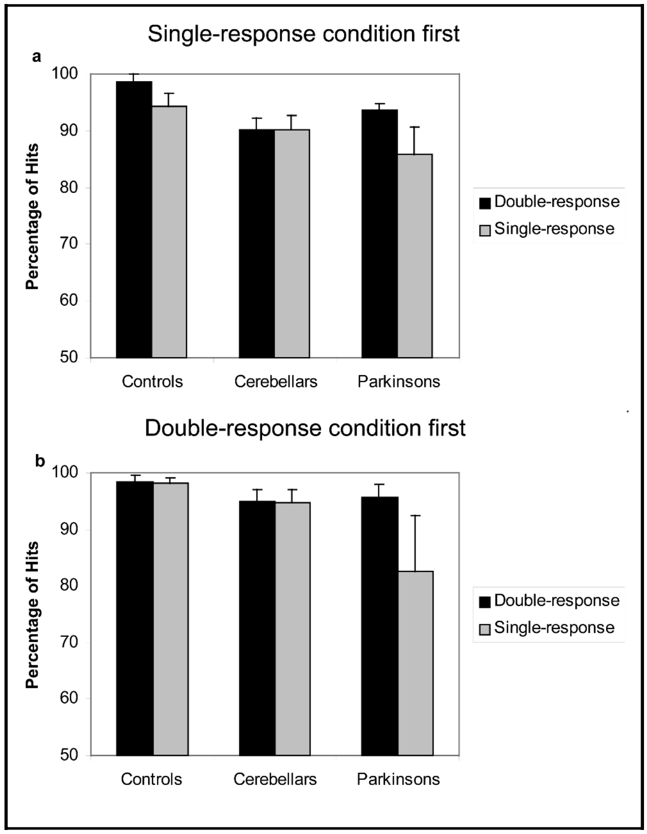

Figure 7. Percentage of hits at the long ITI in the double- and single-response conditions when presented with the (a) single- or (b) double-response condition first. Hit rates are presented only for the first single-response condition (either color or pitch) in part (a), but are averaged across single-response conditions in part (b).

In summary, the problem for the Parkinson patients in the long ITI condition indicates a problem in maintaining attentional set for an extended period. The post hoc analyses described above suggest that the unexpected cost for the Parkinson group may, in part, be related to a problem in inhibiting responses to targets that had previously required a response. Patients who were initially tested on the double-response condition were more likely to fail to respond to the relevant dimension in the single-response conditions, suggesting residual interference from stimuli that had previously required responses.

GENERAL DISCUSSION

There has been a recent explosion of interest in the neural systems involved in executive functioning. While the role of prefrontal cortex in such functions has been recognized for many years, the literature currently emphasizes that such functions entail a distributed network, encompassing both cortical and subcortical structures. Ten years ago, the functions of the basal ganglia and cerebellum were essentially restricted to discussions on motor control. However, anatomical studies have demonstrated that the output from both structures project to prefrontal cortex, and neuropsychological and neuroimaging studies have implicated the basal ganglia and cerebellum in nonmotor aspects of cognition. The challenge for current research is to develop and test functional hypotheses for how these subcortical structures contribute to executive control operations.

Courchesne et al. (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992) have taken the important step of specifying one such functional hypothesis. Building on the cerebellum's role in coordinating skilled movement, they have proposed that the ascending projections of this structure are important for coordinating rapid shifts of attention. The current studies were designed to extend this work by examining the generality and specificity of their findings. We tested adult patients with acquired cerebellar disorders to see if they would exhibit similar deficits as have been found in developmental populations. Moreover, patients with Parkinson's disease were tested on the same protocols to provide a direct comparison of the effects of cerebellar and basal ganglia pathology on attention shifting tasks. The inclusion of the Parkinson group is important given recent studies implicating this structure in the control of attentional set (Hayes et al., 1998; Rogers et al., 1998; Eslinger & Grattan, 1993; Owen et al., 1993; Downes et al., 1989; Gotham et al., 1988; Taylor et al., 1986). Direct comparisons between patient groups are essential for developing hypotheses concerning the specific functions of different neural structures, as well as understanding how such systems operate in an integrated manner.

In general, the results of Experiment 1 provide additional evidence that patients with cerebellar pathology are impaired on a task requiring shifts of attention between two sensory channels. Similar to the developmental findings, the performance of patients with cerebellar lesions was most impaired on the alternating attention condition when the interval between successive targets was relatively short. Compared to Courchesne's studies of children with either acquired cerebellar lesions or autism, our adult subjects were more accurate in the alternating attention condition, and performed at ceiling levels at the long ITI. Thus, the Group × ITI interaction only approached significance reflecting the fact that the potential for improvement was limited for our adult cerebellar subjects.

While Experiment 1 provides an important replication, the results for the Parkinson patients, as well as the results of Experiment 2, suggest that caution should be exercised in assigning a central role to the cerebellum in coordinating rapid shifts of attention. The fact that the Parkinson patients exhibited similar impairments as the patients with cerebellar damage emphasizes that this task does not uniquely identify a functional deficit associated with a particular neuropathology. At the very least, the results indicate that an equally plausible argument could be that the basal ganglia are important for coordinating such shifts. Moreover, we suspect that patients with lesions of prefrontal cortex would likely exhibit a similar pattern.

The finding of similar deficits in diverse neurological groups is, of course, not uncommon. Indeed, a hallmark of the recent surge in neuropsychological reports of cognitive deficits in patients with either basal ganglia or cerebellar pathology is the fact that the performance of these patients is similar to that observed in patients with prefrontal damage (Daum & Ackermann, 1997; Gotham et al., 1988). These commonalities emphasize that the basal ganglia and cerebellum are likely part of an integrated network for the complex processes associated with executive functions. However, until a clear pattern of dissociations is obtained across the patient groups, it is difficult to specify the functional contributions of different neural regions. It may be that such specification is not possible. Functions such as coordinating rapid shifts of attention may emerge as a result of processing across diverse neural regions. Alternatively, our theorizing may be limited by the sensitivity of our tasks.

Experiment 2 was designed to examine in closer detail the demands of the alternating attention task. The experiment was inspired, in part, by contradictory results from our laboratory. Whereas Experiment 1 indicated that patients with cerebellar lesions were impaired in rapidly shifting attention between different perceptual dimensions, Helmuth, Ivry, and Shimizu (1997) had failed to observe any such deficit on a series of attention shifting tasks. An important feature of the Helmuth et al. studies was that each trial required a discrete response rather than a continuous series of responses in the alternating attention condition. This led us to suspect that the attention deficit for the cerebellar patients might be related to a resource problem in the sense that when motor requirements are high (when successive responses occur in rapid succession), there may be fewer resources available for coordinating complex, nonmotor mental operations. A similar hypothesis seemed applicable for the Parkinson group given their motor problems. Thus, we sought to keep the attention shifting requirements constant while varying the motor requirements.

This manipulation did reveal a dissociation between the two patient groups. The performance of the cerebellar group improved significantly when the motor demands of the attention-shifting task were reduced. It is important to note that this group still continued to miss more targets than the control participants. However, this deficit was comparable for both the short and long ITIs. These results suggest that the contribution of the cerebellum is not specific to coordinating rapid shifts of attention. Rather, the performance deficit here appears to arise from the interaction of the motor and cognitive demands required in the alternating attention task, and that this deficit will be most pronounced when the motor demands are high. This account is reminiscent of the informal reports of patients with cerebellar dysfunction that they frequently feel mentally fatigued because of the increased effort in producing and monitoring their movements. By this view, their deficits on cognitive tasks may be an indirect consequence of their motor problems rather than resulting from a deficit in a specific cognitive ability such as attentional shifting.

A similar hypothesis may apply to the children with acquired cerebellar pathology in the earlier study of Akshoomoff and Courchesne (1992). However, it remains to be seen if this motor-based account would apply to the autistic individuals with cerebellar pathology. These subjects do not generally show evidence of cerebellar dysfunction on tests of motor control. Cerebellar dysfunction may have different consequences when the pathology arises early in development. For example, early cerebellar damage may disrupt the development of normal pathways involved in the control of attention. After these circuits have stabilized, damage to the cerebellum may have minimal consequences on attentional function.

In contrast, the Parkinson patients showed essentially no improvement in shifting attention, regardless of whether they were required to respond to all targets or just targets on a single dimension. Given that the attentional requirements were similar in both conditions, this pattern is consistent with the hypothesis that these patients have a specific deficit in coordinating rapid shifts of attention. The current findings thus provide novel evidence of a deficit in Parkinson patients in the control of attentional set. They add to the findings from numerous other studies indicating that the basal ganglia are important in shifting attention, perhaps in a manner analogous to how these nuclei contribute to shifts in motor set (Hayes et al., 1998; Rogers et al., 1998). A puzzling aspect of the results, however, raises one caveat. The Parkinson patients actually performed more poorly in the single-response condition when there was a long interval between successive targets. Not only did they have a problem in responding to designated targets, but they also showed an increase in false alarms in the single-response condition, responding to targets on the dimension not requiring overt responses. This deficit may reflect a problem for the Parkinson patients in inhibiting responses and/or sustaining an attentional set in addition to their problem with shifting attention.

METHODS

Participants

A total of 16 patients with cerebellar lesions, 14 patients with a diagnosis of idiopathic Parkinson's disease, and 9 age-matched control subjects were tested in these experiments. Ten cerebellar patients exhibited focal lesions to either the right (n = 6) or left (n = 4) cerebellar hemisphere (Figure 8). Of the remaining six cerebellar patients, all presented clinical and neuroradiologic findings consistent with bilateral cerebellar

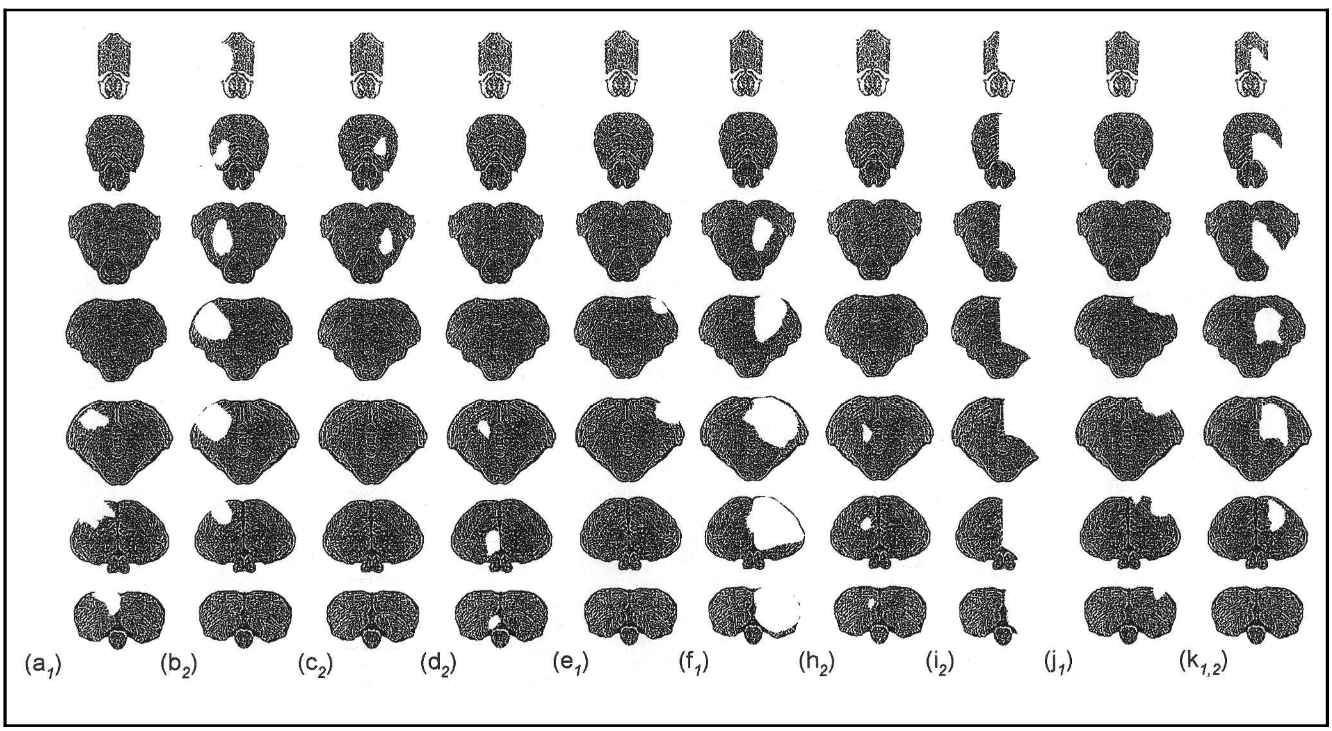

Figure 8. Site and extent of focal lesions for ten cerebellar subjects tested in Experiments 1 and 2. Subscripts indicate the experiment in which the patient participated.

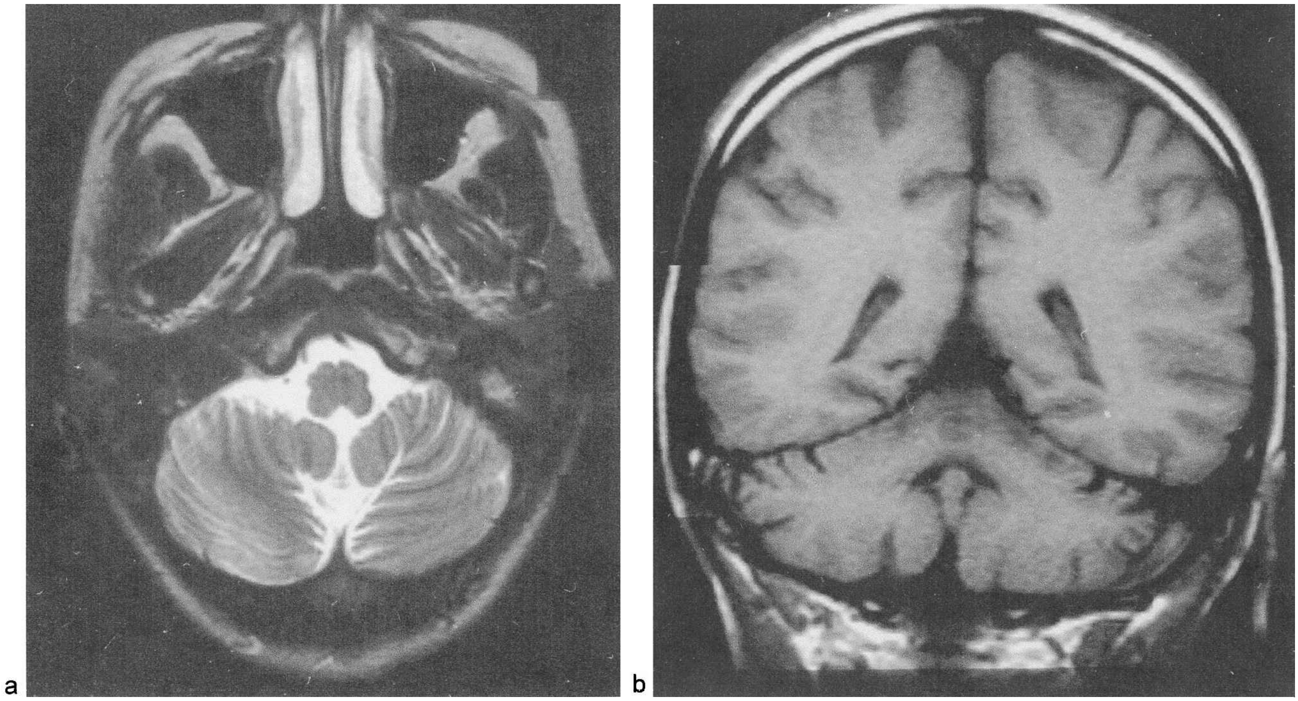

Figure 9. MRI scan of a typical patient with bilateral cerebellar atrophy.

atrophy (Figure 9). Genetic testing was only available for one patient and indicated a variant of spinocerebellar atrophy, Type VI (SCA6). This disorder is associated with atrophy that is restricted to cerebellar structures (Keoppen, 1998; Satoh et al., 1998) and the MRI scan for this patient revealed marked vermal and hemispheric atrophy, with no indication of atrophy extending to other cortical or subcortical structures. All Parkinson patients (PD) were tested while on their normal medication schedules. Three of the 14 patients had undergone a pallidotomy or thaladotomy (see Table 1).

The average age of control subjects was 66 years (*SD* = 5.5), with 58 years (*SD* = 13) being the average age of the cerebellar patients and 63 years (*SD* = 10.2) for the Parkinson patients. Neither patient group significantly differed in age from the control group. At least 85% of each patient group completed the Mini-Mental inventory and achieved near-perfect scores (cerebellars = 29.3 and PD = 29.1 out of a possible score of 30). None of these patients exhibited evidence of dementia as all scored above the criterion of 24 points. Seventy-five percent of cerebellar patients, 57% of Parkinson patients, and 89% of control subjects completed the digit span, vocabulary, and information subscales of the Wechsler Adult Intelligence Test. There were no significant differences between any of the groups on the vocabulary or information subscales. On the digit span test, Parkinson patients performed as well as controls. In contrast to findings of unimpaired performance by cerebellar subjects on verbal short-term memory tasks (Daum et al., 1993; Fiez, Petersen, Cheney, & Raichle, 1992; Bracke-Tokmitt et al., 1989), our cerebellar patients tended to have lower scores compared to controls on the digit-span subscale although the ANOVA failed to reach significance [$F(1,18) = 4.29, p = .053$].

For Experiment 1, eight subjects with confirmed lesions of the cerebellum, nine subjects with Parkinson's disease, and eight age-matched controls were tested. Five of the cerebellar patients suffered unilateral damage extending into the neocerebellum as a result of stroke or tumor resection (one left-sided, four right-sided) while the remaining three exhibited bilateral cerebellar atrophy. For one of the atrophy patients, the pathology appeared to be restricted to the vermal region, whereas for the other two, the atrophy encompassed both vermal and hemispheric regions. Two Parkinson patients had undergone a pallidotomy or thaladotomy. In Experiment 2, patients consisted of 10 cerebellar, 9 PD, and 9 control subjects. Unilateral damage due to stroke or tumor resection was manifested by six of the cerebellar patients (three left-sided, three right-sided). Four of the cerebellar subjects suffered bilateral cerebellar atrophy (one vermal, two neocerebellar, one vermal and neocerebellar). Three Parkinson patients had undergone a pallidotomy or thaladotomy.

Procedure

Two auditory stimuli (500- and 2000-Hz tones) and two visual stimuli (red and blue squares) were presented in

Table 1. Disease Duration, Type, and Hoehn and Yahr Scores for Parkinson's Disease Patients in Experiments 1 and 2

Patient	*Years Since Onset*	*Surgery*	*Symptoms When Medicated*	*Hoehn and Yahr Stage*	*Experiment*
1	14		bradykinetic	1.5	1
2	9		bradykinetic	not available	1
3	16	pallidotomy	bradykinetic	4	1 and 2
4	5		bradykinetic	3[a]	1
5	11	pallidotomy	dyskinetic	2	1 and 2
6	13		bradykinetic	4	1
7	9		bradykinetic	2	1 and 2
8	14		dyskinetic	2.5	1 and 2
9	14		bradykinetic	2[a]	1
10	6	thaladotomy	bradykinetic	2.5	2
11	14		bradykinetic	2.5	2
12	>10		bradykinetic	4	2
13	12		dyskinetic	3	2
14	16		bradykinetic	3	2

[a]Assessment was with the Unified Parkinsonism Rating Scale. Hoehn and Yahr scores were estimated from the UPRS.

random order for 80 trials per block. The low-pitch tone and the red square were designated as targets, and each occurred with 17% probability. The distractors, blue squares and high-pitch tones, were each presented 33% of the time. Subjects were instructed to press a button with the index finger of their less symptomatic hand every time a target occurred. Stimulus duration was 100 msec and stimulus onset asynchrony (SOA) varied randomly between 450 and 1450 msec.

In the two focused attention conditions of Experiment 1, subjects performed five consecutive blocks during which they were required to respond to all occurrences of the low-pitch tone (Focused Pitch) while ignoring all other stimuli and five blocks in which they were to respond to each occurrence of the red square (Focused Color). In the alternating attention condition, subjects were instructed to alternate between the dimensions, responding to a target in one modality and then a target in the other modality and so forth. Thus, targets in the attended modality not only required a response, but also served as a cue to switch attention to the other modality. Subjects completed 10 consecutive blocks of this task. For each participant, one dimension was always designated as the starting dimension, with this factor counterbalanced across participants.

All subjects completed practice blocks for each condition until they understood the instructions and felt comfortable with the task. The order of presentation of the three experimental conditions was counterbalanced across subjects.

For Experiment 2, the participants were tested on three versions of the alternating attention tasks. The double-response condition was identical to that used in Experiment 1: The participants responded to each target, alternating between the visual and auditory dimensions. For the single-response conditions, the task was modified into a go–no-go format to reduce the response demands. The attentional requirements were unchanged, with the participants alternating between the two dimensions following the detection of a target. However, they were only required to make overt responses to targets on one dimension. Two versions of the single-response condition were tested, one in which overt responses were required on the visual dimension and one in which overt responses were required on the auditory dimension. Fifteen blocks were tested for each of the single-response conditions in order to obtain a sufficient number of observations for each of the ITI bins (see below). As in Experiment 1, practice was provided prior to each condition and the order of the three conditions was counterbalanced across subjects.

Data Analysis

To compensate for any possible slowing of patient responses, we used a rather liberal criterion in our definition of a hit, the successful detection of a target. A response was scored as a hit if it occurred between 200 and 5000 msec after target onset. To obtain a more sensitive measure of accuracy and to ensure a normal distribution, an inverse sine transformation of the scores was used for all statistical analyses. False alarms to targets and distractors were tabulated. Since false alarms to distractors were very rare and equivalent in the three groups, they were not analyzed further. However, the false alarm rates of the patients to target stimuli did not appear comparable to the controls and so were subjected to further analyses. Note that false alarms in these experiments correspond to responses to a target stimulus when that dimension is not the focus of attention (i.e., responding to two straight red targets in the alternating attention condition). In the single-response conditions, only false alarms made to targets of the dimension requiring a manual response (either the red square or the low-pitch tone) were measured since the hit rate for these conditions was composed only of responses to that dimension.

The percentage of hits was used as our measure of switching accuracy without the subtraction of false alarms in order to be comparable to previous work (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992, 1994). On theoretical grounds, hit rate was thought to more accurately measure subjects' abilities to switch attention to new stimuli while false alarm rate was conjectured to be more reflective of the ability to inhibit previously relevant items. Switching difficulty may be affected by the ability to inhibit attention to the irrelevant dimension, but it is inappropriate to combine these dissociable processes into one measure. Regardless, analyses were run using both hit and hit–false alarm rate. With one exception, the results of both experiments were the same using either measure. The exception occurred in Experiment 1 where the marginal effect of attention (divided/focused) using hit rate became significant for controls when using hits–false alarms.

Following the convention established in earlier studies with this task (Courchesne et al., 1994; Akshoomoff & Courchesne, 1992), we divided the trials into those in which the onset of successive targets occurred in rapid succession (< 2.5 sec) and those in which there was a longer interval between target onsets (ranging from 2.5 to 30 sec). Hits and false alarms were assessed at these two ITIs. As we were testing the hypothesis in Experiment 2 that the production of rapid successive movements disproportionately affects the performance of the patients, hits and misses were not tabulated after an instance of a false alarm. Tabulation did not resume until a correct response was obtained on a target stimulus.

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