Acta Psychologica 116 (2004) 285–307

acta psychologica

www.elsevier.com/locate/actpsy

Resistance to the impact of interruptions during multitasking by healthy adults and dysexecutive patients

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Received 13 August 2003; received in revised form 19 April 2004; accepted 19 April 2004

Abstract

Two experiments (one with healthy adult volunteers and the other with controls and dysexecutive patients) assessed the impact of interruptions on a novel test of multitasking. The test involved switching repeatedly between four tasks (block construction, bead threading, paper folding, alphabetical searching) over a 10 min period. In Experiment 1, there were four groups of 20 healthy participants. One group attempted multitasking with no interruption, a second group was interrupted early in the test, a third group late in the test and a fourth group was interrupted both early and late. Interruption involved carrying out a fifth, unexpected task for a period of 1 min before returning to the four main tasks. There was no difference in multitasking performance between the groups. In Experiment 2 the participants were seven dysexecutive patients and 14 age-matched controls. A repeated measures approach was employed to assess the impact of two interruptions (early and late) for both groups. Contrary to predictions, the patients as well as controls were resistant to the effects of interruptions, despite their clearly impaired multitasking performance. These results suggest that the ability to deal with interruptions may be separable from the ability to organise and execute multiple tasks within a limited time frame.

PsycINFO classification: 2340—Cognitive Processes
Keywords: Multitasking; Dysexecutive syndrome; Interruptions

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0001-6918/$ - see front matter
doi:10.1016/j.actpsy.2004.04.003

1. Introduction

The term "multitasking" can be used to apply to a situation where a person is engaged in multiple discrete tasks within a limited time frame (but must switch back and forth between them) rather than a situation where he or she is attempting multiple tasks simultaneously. Burgess (2000) has provided a detailed description of the features involved in this kind of multitasking situation, prototypical examples of which are cooking a meal, or carrying out a range of errands in a shopping centre. Multitasking has so far been studied in the neuropsychological literature by contrasting the performance of brain lesioned patients with that of matched controls, on tests designed to tap similar cognitive processes to those involved in real life multitasking. Examples are the Six Elements Test and the Multiple Errands Test (Shallice & Burgess, 1991), the Strategy Application Test (Levine et al., 1998) and the Greenwich Test (Burgess, Veitch, de Lacy Costello, & Shallice, 2000).

However, the type of multitasking test used in the neuropsychological literature has not been widely applied with samples of healthy adults to determine the variables that may affect multitasking ability. As a result, very little is known at an empirical or at a cognitive theoretical level as to how multitasking is achieved by healthy individuals, and what factors might constrain or impair successful multitasking performance. One potentially important variable is whether an external interruption occurs during the test. Interruptions were one of the features identified by Burgess (2000) as characteristic of a multitasking situation. Despite this, studies that have examined the multitasking deficits of patients have not tested the ability of patients to deal with externally imposed interruptions during these kinds of tests. Therefore in the experiments reported here, both healthy adults and dysexecutive patients are interrupted during a test of multitasking in order to determine whether this disrupts their performance.

Interruptions have been studied in other multitasking contexts with healthy adults, because in many different types of occupational settings, for example emergency medicine (Chisholm, Collison, Nelson, & Cordell, 2000) or aviation (Latorella, 1999), interruptions are seen as an inevitable and integral part of the job, but may in turn cause disruption to on-going task performance. While it is important to identify what can cause disruption in critical occupations, it may not necessarily reveal a balanced picture of human cognitive abilities. It could be that people are actually quite skilled at dealing with interruptions, and are only disrupted on a small percentage of occasions. The effect of interruptions on computer multitasking and other computer use has been studied a great deal in the Human Computer Interaction literature (see McFarlane & Latorella, 2002, for a review). The primary goal of much of this research has been to design better user interfaces. However, a number of studies that have focused more on human cognition have provided some insight into the properties of interruptions that determine whether they will be disruptive.

One long established effect of interruptions is the Zeigarnik effect (Zeigarnik, 1938). Zeigarnik found that participants were more likely to remember tasks that had been interrupted than those that had been completed (but see Van Bergen, 1968). Zeigarnik argued that the strong memory for interrupted tasks was due to what Lewin (1951) had described as a "internal tension-state" that drives people to finish uncompleted tasks.

Gillie and Broadbent (1989) reported four experiments which examined the effect of interruptions on an on-going computer "errands" task. The scenario presented to the participants had a limited number of locations which had to be searched for objects from a memorised list. Gillie and Broadbent manipulated the duration of the interruption, the similarity of the interruption to the main task, the complexity of the interruption task and the opportunity for participants to rehearse information from the main task before dealing with the interruption. They concluded that on-going task performance is more likely to be disrupted if the interruption is complex, or similar to the on-going task. Length of the interruption and what they describe as "the opportunity to rehearse" were not considered to be important factors. However, McFarlane and Latorella (2002) point out that "opportunity to rehearse" was also not manipulated alone between any of the experiments, and therefore no conclusions can be drawn about the impact of rehearsal opportunities from Gillie and Broadbent's experiments. Also, because the interruption always occurred at the same point in any interrupted problem, participants could have come to expect it and prepare themselves.

A study by Edwards and Gronlund (1998) investigated how people recover from an interruption to a primary task using an experimental task that was very similar to that of Gillie and Broadbent (1989). Like Gillie and Broadbent, they manipulated the similarity of the interruption task to the main task. However, the focus in Edwards and Gronlund's experiment was on memory for the list of items after the interruption rather than execution of the errands. Edwards and Gronlund's results agree with Gillie and Broadbent's in that they found that the similar interruption had a more disruptive effect than the dissimilar interruption.

A study by Zijlstra, Roe, Leonora, and Krediet (1999) examined the effect of interruptions on a text editing task in two experiments. They predicted that the disruptive effect would increase as they manipulated frequency and complexity of the interruptions, but they also thought that the participants would develop strategies to cope with the interruptions. Simple interruption tasks involved looking up a piece of information, while complex interruption tasks involved doing a short piece of editing on a different document. Therefore complex interruptions were also similar to the main task, confounding these two variables. Unlike the two studies discussed above (Edwards & Gronlund, 1998; Gillie & Broadbent, 1989) in Zijlstra et al.'s experiment neither simple nor complex interruptions had a negative effect on performance. In fact, interruptions actually caused participants to speed up performance of the text editing task with no loss of accuracy. Therefore interruptions did cause a change in people's strategies, as they appeared to be trying to "make up for lost time".

This speeding up of on-going task performance after interruption can also be seen in an experiment by Speier, Valacich, and Vessey (1999), who set out to investigate the effects of task interruption on individual decision making. The undergraduate participants in their two experiments had to make decisions based on problems related to industrial scenarios and were interrupted with "information acquisition tasks". Speier et al. found that simple tasks were completed more quickly when they were interrupted, with no loss of accuracy. Complex tasks were disrupted by the interruption (both in terms of accuracy and speed), more frequent interruptions had a greater disruptive effect, and when the interruption task was dissimilar to the main task the decision time increased but decisions were equally accurate.

This last finding (that an interruption that is dissimilar to the main complex task slows down performance) contrasts with the findings of both Gillie and Broadbent (1989), and Edwards and Gronlund (1998), who found that similar tasks were more disruptive. However in Speier et al.'s (1999) experiment, it is possible that there was less necessity than in the previous studies for participants to hold the content of the on-going task in memory during the interruption. Speier et al. argue that the dissimilar content is disruptive because it demands extra information processing operations from the ones that have already been in use. Therefore there could be a greater "switch cost" involved than when the interruption was similar.

Eyrolle and Cellier (2000) conducted a field study in a telecommunications office, in which they found that interrupted tasks took longer to complete on average than non-interrupted tasks. Telephone operators took longer to process a task if they were interrupted by a telephone call, however they did not make more errors. If they were interrupted twice, tasks took significantly longer again than if there was only one interruption. This is consistent with Speier et al.'s (1999) finding that performance time on their task increased as interruption frequency increased.

There is a relative lack of published, well controlled experimental studies on this topic, but from the limited data available, it appears that interruptions can have a deleterious effect on performance of both single tasks (Eyrolle & Cellier, 2000; Speier et al., 1999) and on "errand" tasks that, although simplified, have some similarities to a multitasking situation (Edwards & Gronlund, 1998; Gillie & Broadbent, 1989). However, they also show that interruptions will not inevitably disrupt performance and can even be beneficial in certain circumstances (Speier et al., 1999; Zijlstra et al., 1999). It seems that the disruptive effect of interruptions will depend on the interaction of factors associated with both the interruption task and the main task.

In the experiments reported here, the aim was to use a similar approach to studying multitasking as in the neuropsychological literature. One study (Manly, Hawkins, Evans, Woldt, & Robertson, 2002) has tried combining this approach with interrupting "alerts" (brief auditory tones) that occurred at unpredictable intervals during a test of multitasking. Manly et al. found that these alerts improved the performance of 10 traumatic brain injury patients, who were specifically told to use them as reminders to think about what they were currently doing and what their overall goals were. It is not clear that the interrupting alerts would have had the same effect if they had not been explicitly associated with goal evaluation in the task instructions. Also, these were not interruptions in the same sense of the other research reported above, as the alert did not require the participant to break away from what they were doing and turn to a different task, and Manly et al. show that the patients did not spontaneously use the tones as a signal to switch sub-tasks in this manner. Therefore, there is little previous research from which to draw predictions about how interruptions that require an extra task to be dealt with will affect on-going multitasking performance.

The effect of unexpected interruptions on a test of multitasking was examined for healthy adults in Experiment 1, and for dysexecutive patients (with matched controls) in Experiment 2. One account might suggest that patients would find the interruptions more disruptive than would the healthy adults, as previous evidence shows that patients have trouble switching between different tasks in a multitasking situation and in applying an effective strategy overall (Burgess, 2000). The interruption could overload them further by imposing another demand to switch tasks. However, an alternative account would be that the cognitive processes involved in making a self-initiated switch from one task to another are quite different from those involved in dealing with an unexpected, immediate demand from an external source, before returning to the on-going task. In this case, we might expect dysexecutive patients to perform more poorly than controls on multitasking, but they need not necessarily show any particular sensitivity to the effects of interruptions.

The test used in the present experiments was based on the Greenwich Test described by Burgess et al. (2000). In the Greenwich Test, participants have three sub-tasks to attempt within a limited time period, and have to apply an efficient strategy to collect items of a specific colour in each sub-task in order to obtain a high score overall. In order to maximise the possible disruptive impact of the interruption, the interruption task was unexpected and unrelated to the on-going situation. To increase the immediacy of the interruption, the interruption task was selected to reduce what Altmann and Trafton (2002) term the "interruption lag"; that is, the delay between an alert that an interruption is about to happen, and the interruption task itself. Trafton, Altmann, Brock, and Mintz (2003) have shown that participants who were given an 8 s interruption lag could resume the primary task more quickly than those for whom there was no interruption lag. Given that the interruption is unexpected in our experiment, some time is required to explain the interruption task to participants. The task used here was selected to minimise this delay and involved writing down the names of pictured objects.

In Experiment 1, we might expect (e.g. Gillie & Broadbent, 1989) a disruptive effect on performance. Based on the results of Speier et al. (1999) and Eyrolle and Cellier (2000), we might also expect that, two interruptions would be more disruptive than one. However, the work by Zijlstra et al. (1999) might suggest that interruption will have little if any deleterious effect. A separate prediction is that, after the interruption, participants may tend to return to the sub-task on which they were working before the interruption. This tendency to return to an interrupted task was observed in experiments by Ovsiankina (1928) and also by Smith, Hill, Long, and Whitefield (1997) during an observational study of secretarial office administration. It would also be predicted by the Zeigarnik effect, as the interrupted sub-task should be prominent in memory.

2. Experiment 1

2.1. Method

2.1.1. Participants

Participants were 80 first year psychology undergraduates at the University of Aberdeen, who received course credit for taking part. They were allocated at random to four groups of 20 participants, with roughly equal proportions of males and females in each group. The mean age was 19.99 years (SD = 5.88), with 39 males and 41 females.

2.1.2. Design

The four independent groups of participants worked on a test of multitasking for 10 min. One group was interrupted 3 min into the test, another was interrupted 7 min in, while a third was interrupted at both 3 and 7 min. The fourth (control) group was not interrupted during the multitasking test.

2.1.3. Materials and tasks

The multitasking test consisted of four sub-tasks, some of which were based on modifications of the tasks used by Burgess et al. (2000). In that study, participants were told that items in each sub-task that were coloured red were worth extra points. The general instructions given to the participants in our study were as follows: "Your aim in this experiment is to score as many points as possible over four tasks in 10 minutes. You must attempt at least part of all the tasks, but the time is too short for you to complete them. You may perform the tasks in any order and may switch between them at any time and as often as you like. In all tasks, RED items are worth 10 POINTS, while items of any other colour are only worth 1 POINT." These instructions were written on a General Instruction sheet, along with a description of how to attempt each sub-task. The sub-tasks were as follows:

Telephone task: A telephone directory and a list of 20 names taken from throughout the residential section—five of the names on the list were marked out in red. A label marked the beginning of the Residential section of the phone book. Participants had to look up the telephone numbers corresponding to the names on the list and write them down. They were instructed that they could do this in any order they wanted, therefore a strategic approach to the test involved first looking up the five names printed in red ink.

Brick construction task: Participants were presented with a structure built from Lego™ bricks comprising a (8 cm × 8 cm × 12.5 cm) square tower with a hollow centre made with 13 layers of eight 2×4 bricks (or relevant number of 2×2 bricks) in each layer. All of the bricks within a single layer were of the same colour, but colour varied across layers, and no two consecutive layers were of the same colour. The 2nd, 6th and 11th layer from the bottom were constructed of red bricks. A tub containing sufficient bricks of the right colours to replicate the tower was available. Participants were instructed to construct a tower of the same shape, although 2×4 bricks could be replaced by two 2×2 bricks, and vice versa, providing that the tower construction was stable. Participants were told that points would be awarded for every complete layer (not every brick), therefore a strategic approach to this task was to complete a red layer before switching to another sub-task.

Envelopes task: There were 25 sheets of A4 size (21 cm × 29.6 cm) paper in three piles in front of the participant, one pile had 10 sheets of blue paper, another had 10 sheets of yellow and another had five red. There was also a sufficient number of letter (11.4 cm × 23.4 cm) envelopes. Participants were instructed to place as many sheets as possible in the envelopes provided, one sheet per envelope, folded into thirds (like a letter). They were told they could select the paper in any order, therefore the best strategy for this task was to first use up the red pile of paper before moving to the lower-scoring colours. They were instructed not to seal the envelopes.

Beads task: An example series of beads threaded on to a piece of string (approximately 55 cm long) was provided for the participants. The series of beads comprised 26 sections of colour, with each section made up of three beads. The red sections were the 2nd, 6th, 12th and 19th, starting from the left end of the string as viewed by the participant. Ordinary 0.2 cm thick string was used, and the beads were Galt Toys™ threading beads (0.9 cm in diameter with a 0.4 cm hole in each for threading). The participant was presented with a piece of string (approximately 55 cm long) and an open box containing sufficient beads to replicate the example. A larger bead (2 cm in diameter) was tied at the end of the participant's piece of string and indicated the correct end to start, as an identical one was used in the example. The task was to thread the beads with the colours in the same order as shown. As in the Lego™ task, a strategic approach to this task involved completing a red section of beads before moving on to another sub-task. Participants were instructed only to take one bead out of the box at a time.

Additional materials: A large silent digital stop clock was clearly visible for participants to keep track of time. Stopwatches were used by the experimenter to keep track of the time for the multitasking test, and to time the interruptions. When they were interrupted, participants were asked for 1 min to write down the names of pictures of everyday objects, using the first 100 pictures from Snodgrass and Vanderwart (1980).

2.1.4. Procedure

The tasks were spread across a large desk, about 10 cm apart. The order in which they were laid out was counterbalanced across participants. Participants were informed that they had to attempt all the sub-tasks in 10 min, but that they could do them in any order and switch back and forth between them as often as they liked. An instruction sheet described how to attempt each task, explained the higher points value of red items, that the aim was to score as many points as possible, that they would lose all the points accumulated in a task if they broke a rule, and that they would lose 100 points if they missed out a sub-task. After reading the instruction sheet the participant was asked to recall everything they could about the instructions. They were then asked a series of 12 cued recall questions which covered the most important points (see Table 1). If they did not know an answer it was explained to them. Participants then began the multitasking test, during which the stop-clock

Table 1
Cued recall questions in Experiments 1 and 2

Questions for Experiment 1 and Experiment 2 (The questions were presented in Italian in Experiment 2)
1. How long do you have for the whole test?
2. How many of the tasks should you attempt? (but you do not have to finish them)
3. Do you have to attempt the tasks in any particular order? (and you can switch as often as you like)
4. What are you aiming to do in this test?
5. Which colour of item is worth 10 points in all the tasks?
6. Do you have to find the telephone numbers in any particular order?
7. How are points awarded for the Lego™ task?
8. Do you have to fill the envelopes with coloured paper in any particular order?
9. What should you not do with the envelopes?
10. How many beads can you take out of the box at one time?
11. What happens if you break a rule on one of the tasks?
12. What happens if you miss out a task?
Extra questions for Experiment 2:
What should you do every time you switch between 2 of the tasks?
Do the Lego™ bricks you use have to be exactly the same size as in the example?
How are points awarded for the beads task?

was situated about 80° to the left, so that the participant had to turn their head to view the elapsed time. Participants who were interrupted turned 90° to the left for the picture-naming task, so that the multitasking materials were not directly in view during the 1 min interruption. When 10 min had elapsed on the multitasking timer (which was paused during the interruptions), participants were again tested with both free and cued recall of the task instructions. They were also asked to report any strategies they had adopted. The experimenter recorded the tasks attempted, the number of items completed on each, and rule breaks.

2.2. Results

The main goals of Experiment 1 were to explore whether interruptions would have a negative effect on performance, and whether two interruptions would be any more disruptive than one. We also explored whether an early interruption would be more likely to be disruptive than one that came late in the test. Data from one participant were excluded because of a failure to remember more than 25% of the task instructions during initial free recall.

The first measure was of multitasking efficiency, taken as the proportion of completed items that were red, given that these items were worth 10 points rather than one. The mean performance of each group, averaged across the four sub-tasks of the multitasking test, can be seen in Table 2. A one-way ANOVA showed that there were no differences between the groups in terms of multitasking efficiency averaged across all four sub-tasks, $F(3,79) = 2.294$, ns, $MSE = 0.016$. An examination of effect-size revealed an Eta squared of 0.083, suggesting a medium sized effect (Clark-Carter, 1997).

Table 2
Table of group means in Experiment 1 for the proportion of completed items that were red, and the total proportion of items completed

Group	Proportion of red mean (SD)	Total proportion mean (SD)
1—Not interrupted	55.5% (11.0%)	32.9% (7.5%)
2—Early interruption (at 3 min)	45.7% (13.1%)	39.0% (6.4%)
3—Late interruption (at 7 min)	49.6% (15.3%)	32.1 (9.3%)
4—Two interruptions (at 3 and 7 min)	47.2% (11.4%)	37.9% (9.2%)

The first measure examined the efficiency with which participants selected which items to complete (red = higher score). The second analysis examined overall performance as measured by the proportion of the available items that were completed by the participant, regardless of colour. This offers a measure of speed in executing the sub-tasks, and was examined because previous studies had found that interruptions can speed up performance in certain circumstances (Speier et al., 1999; Zijlstra et al., 1999). For this measure, the one-way ANOVA showed that there was a significant difference between the groups, $F(3,76) = 3.589$; $p < 0.05$, MSE = 0.007, with the early interruption group and the two interruptions group tending to complete more items across all tasks than the other two groups, as can be seen in Table 2. Post hoc Tukey HSD tests were conducted, which showed that the only significant difference lay between Groups 2 and 3 ($p = 0.047$). Therefore, the group that was interrupted at 3 min completed more items of all colours than the group that was interrupted at 7 min.

Interruption task performance: The performance of participants on the interruption picture-naming task was examined for errors (either missing out a picture label or giving an incorrect one). The error score is expressed as a percentage of the pictures attempted during the interruption (or two interruptions for Group 4). The range in this score was from 0% to 67% with a median value of 10.1%. The wide range of scores arose from seven participants who generated a large number of errors—this was most likely because their first language was not English. However, this can only have increased the demand of the interruption for these participants, who were distributed across the experimental groups. Only one participant made no errors at all on the interruption task. These scores show that the task was not trivial, being sufficiently demanding to cause errors.

Analysis of post-interruption behaviour: The analysis of post-interruption behaviour showed that on 88% of occasions, participants returned to the sub-task that they had been working on before the interruption, rather than any other sub-task. If they had been equally likely to return to any of the four tasks, only 25% of interruptions would have resulted in participants going back to the one they were working on before. A binomial test showed this effect to be highly significant ($p < 0.001$). A Chi Square test, χ^2 $(1, N = 80) = 0.457$, ns, showed that there was no association between interruption group and the likelihood of returning to the same task following an interruption. Therefore it was not the case that participants in any particular group were more likely to change tasks following an interruption, than were those in the other groups.

Recall of task instructions: The mean free recall score for the task rules before the test was 51.69% (SD = 10.22%). The performance of participants on the cued recall questions was high, with 81.3% of people getting 10, 11 or 12 questions right before the test. This, along with the low number of rule breaks (only four participants broke a test rule), suggests that people did have an understanding of the crucial aspects of the multitasking test before they began. From the free ($M = 62.09\%$, SD = 12.45%) and cued ($M = 94.81\%$, SD = 8.53%) recall measures taken after the test, there was no tendency for one group to score more highly than another (as determined by one-way ANOVA, free recall $F(3,76) = 0.757$, ns, MSE = 0.016, cued recall $F(3,76) = 1.045$, ns, MSE = 0.007). Therefore the interruptions did not appear to affect recall of the instructions at the end of the test. Also it was not the case that the increase in total proportion of items completed for the Early Interruption group was caused by differential recall of the task instructions.

2.3. Discussion

There was no evidence from this experiment that interruptions had a negative effect on the multitasking efficiency of healthy adults. It seems that participants were generally concentrating on the red items (75 out of 80 reported that this was their strategy), but despite performance in both the primary and the interruption task being below ceiling, participants appeared to be unaffected by the presence of an unexpected interruption. As there was a medium effect size for the interruption manipulation in this experiment, a power analysis was conducted. This revealed that to have any chance of observing a disruptive impact, the sample size would have to be very substantially increased (almost doubled). The finding of no (or extremely weak) effects of interruptions on multitasking has been replicated (Law, 2004), and is certainly at odds with the generally held view of interruptions as occurrences that necessarily threaten on-going task performance. Indeed, there was some evidence that interruptions had a beneficial effect on the total proportion of items completed (regardless of colour), a measure of a participant's speed at completing the sub-tasks. There was a tendency for the early interruption and two interruption groups to complete more items. This finding would be consistent with Speier et al. (1999) and Zijlstra et al. (1999), studies which both found that interruptions increased the speed with which participants worked on the on-going task, without a loss of accuracy. An additional finding was that participants were significantly more likely to return to the task they had been working on prior to the interruption than any other task. This finding is examined further in Section 4 following the report of Experiment 2.

Overall the results of Experiment 1 show that healthy adults can be insensitive to interruption when performing a multitasking test. However, the reaction of dysexecutive patients to being interrupted during such a test could be quite different. If they struggled to cope with the test, an interruption could overload them further and cause a greater deterioration in multitasking efficiency. Given the specific nature of the deficits seen in the dysexecutive syndrome however, it could be that patients retain the ability (that healthy adults show in Experiment 1) to deal with a short interruption to the multitasking test with no effect on performance. In addition, although previous studies have shown that multitasking tests on which our procedure was based show impoverished performance in frontal patients (e.g. Levine et al., 1998; Shallice & Burgess, 1991), the precise form of the test that we used has not been used with patients. It would therefore be important to establish that our multitasking test shows similar impaired levels of performance with patients as has been shown previously. This would give us greater confidence that the lack of an effect of interruptions that we observed did not arise from a lack of sensitivity of our multitasking test.

3. Experiment 2

Several neuropsychological studies of multitasking have suggested that some patients with brain damage, especially to the prefrontal cortex, may have specific difficulties in applying an efficient strategy to a multitasking situation (Bisiacchi, Sgaramella, & Farinello, 1998; Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Burgess et al., 2000; Crépeau, Belleville, & Duchesne, 1996; Goldstein, Bernard, Fenwick, Burgess, & McNeil, 1993; Shallice & Burgess, 1991). Such patients can be surprisingly unimpaired in terms of memory, language, perception and IQ as measured by standard tests, and yet have marked difficulties in their everyday lives (Eslinger & Damasio, 1985; Goldstein et al., 1993; Shallice & Burgess, 1991). This pattern of deficits has been called "strategy application disorder" (Burgess, 2000).

There is evidence of a single dissociation between performance on the Six Elements Test (a widely used multitasking test, e.g. Burgess et al., 1998; Crépeau et al., 1996; Shallice & Burgess, 1991) and both the Verbal Fluency Test and the Wisconsin Card Sorting Test (Burgess, 2000; Levine et al., 1998). Patients can have unimpaired performance on the traditional executive measures and yet an inability to multitask effectively. There is very little evidence that patients can show the opposite pattern of impairment. Worthington (1999) did report a patient (JW) with normal performance on the Six Elements Task but clearly impaired executive performance. However, this patient may still have had trouble with more demanding multitasking situations as she did perform poorly on the Multiple Errands Test. In the present experiment, patients were selected for the study on the basis that they had a known executive impairment, rather than on the basis of lesion locality. Therefore a clear impairment on the multitasking test was expected, as there is very little evidence that multitasking ability can remain intact in the face of executive dysfunction.

Given that pure dysexecutive patients are relatively rare, it was not practicable to use the between-subject design that was adopted for Experiment 1. Therefore, the multitasking test was modified for Experiment 2, and a parallel form of the test was created so that interruption condition could be manipulated within-subjects. All participants (patients and matched controls) attempted the task twice, the first time uninterrupted and the second with two interruptions occurring at 3 and 7 min (as for Group 4, Experiment 1). The order of presentation was not counterbalanced because of the limited number of patients involved. However, any disruptive effect of interruptions was set against any beneficial effect of practice, therefore the likelihood of making a Type 1 error was reduced. It was predicted that the patients would perform more poorly than controls in the uninterrupted condition, and then the interruptions would cause their performance to deteriorate further. No effect of interruption on the performance of controls was expected.

Another change to the test was introduced, by adding a prospective memory component. Participants were required to say "changing" (in Italian, "cambio") out loud when they were about to switch between two of the sub-tasks. It was predicted that patients would forget to do this more often than the controls. With regard to post-interruption behaviour, there were two possible predictions—that the patients would be less likely than controls to return to the same task, or that there would be no difference between patients and controls on this measure. If this behaviour is caused by a tension created by unfinished tasks (Lewin, 1951; Zeigarnik, 1938), and is a relatively universal and automatic cognitive process, the first outcome would be more likely. If it were a deliberate strategy to reduce the disruptive effect of the interruption, then it might be more likely that patients would not apply this strategy, and pick up a task at random after the interruption. For all participants, the sub-tasks were placed back into their initial position during the interruption, so that any external cues to remind the participant of what they had been doing prior to the interruption would be much less salient.

3.1. Method

3.1.1. Participants

The experiment took place at the Department of Rehabilitation, Hospital and University of Ferrara, in Italy. Participants in the experiment were seven dysexecutive patients and 14 matched controls. The patients (five males and two females) had suffered either Traumatic Brain Injury or Cerebral Vascular Accident and were aged between 22 and 56 years ($M = 35.71$, $SD = 13.52$). The inclusion criterion for the patients was that they had shown evidence of an executive impairment, by poor performance on either the Wisconsin Card Sorting Test (score of 1 or 0; Laiacona, Inzaghi, De Tanti, & Capitani, 2000), or on the Six Elements Test, (at least one standard deviation below the normative mean of 100, i.e. 84 and below; Spitoni, Antonucci, Orsini, Dolimpio, & Cantagallo, 2002). The scores for each patient are given in Table 3. All patients had been given a battery of 14 perception, attention, language and memory tests by the hospital, which ensured that their executive impairment was relatively pure in nature (they had shown impairment on no more than two of these tasks). All patients' lesions were assessed by CT scan—lesion sites are shown in Table 3 along with the characteristics of each patient.

Fourteen controls (10 males and four females), with two matched to each patient by sex, age and years of education, were selected among hospital staff and acquaintances of the experimenters. None of them had any reported brain damage. The

Table 3
Patient characteristics

Patient	Age	Gender	Years of education	Type of injury	Lesion site	WCST global	Six elements
M.C.	31	Male	13	TBI	Left basal–frontal	1	62.17
A.M.D.	48	Female	13	TBI	Bilateral frontal, right temporo-parietal	1	108.87
L.T.	22	Male	8	TBI	Right fronto-temporal, left parietal	2	77.73
V.G.	23	Male	8	TBI	Bilateral frontal	4	NA[a]
P.G.	56	Male	13	CVA	Left frontal–parietal	1	77.73
E.C.	26	Female	8	TBI	Left fronto-temporal	2	62.17
M.B.	42	Male	8	TBI	Right frontal–parietal	4	77.73

[a] Not assessed because test was too difficult for the patient.

mean age of the control group was 35.93 years (SD = 12.52). The mean education level of the patients was 10.14 years (SD = 2.67), while for controls the mean was 12.29 years (SD = 1.82). The difference between the patients and controls in years of education did not reach significance.

3.1.2. Design

The experiment had a mixed design, with a between-subjects factor of participant group (patient or control) and a within-subjects factor of interruption condition (no interruption or two interruptions).

3.1.3. Materials and tasks

All materials for the multitasking test were laid out on the table before the participant came into the room. The layout of the tasks was counterbalanced so that the position of the tasks on the table would not cause a systematic bias, affecting the task that participants chose to do first. There were two parallel forms of the test—version 1 and version 2. Half the participants were given version 1 in the first condition and half were given version 2 in the first condition. The rules governing the tasks were the same as in Experiment 1, but some extra materials were needed in order to form two versions:

Telephone task: A telephone directory for the local area of Ferrara was provided, along with a separate sheet with a list of 20 names taken from the book. The 2nd, 6th, 9th, 15th, and 20th names were printed in red ink. Different names were used in versions 1 and 2 of the task.

Brick construction task: In version 1 of the test, the structure to be copied was a square tower (8 cm × 8 cm × 11.5 cm) with a hollow centre, made with 12 layers of eight 2 × 4 bricks. The 2nd, 5th and 10th layers were made with red bricks. A tub with sufficient bricks of the right colours to replicate the tower was provided. In version 2 of the test, the tower was a rectangle shape, made with the same number of bricks and with the red layers in the same place.

Envelopes task: There was a pile of 25 sheets of coloured paper on the table along with envelopes. Red sheets of paper were inserted into the pile at positions 2, 6, 12, 16 and 25. Participants were permitted to put the paper into envelopes in any order (so the efficient strategy was to pull out the red sheets first). In version 1 of the test (which was the same as Experiment 1), the paper had to be folded into thirds (like a letter). In version 2 it had to be folded into quarters and put into envelopes of a suitable size (16.4 cm × 11.4 cm). Each therefore required the paper to be folded along two creases, which were made before the first participant attempted the test.

Beads task: In version 1 of the test, the string was made up in 20 coloured sections, with three beads in each section. The 2nd, 6th, 12th and 20th sections were made with red beads. In version 2, there were 30 sections of two beads of the same colour—the 2nd, 4th, 10th, 12th, 20th and 30th sections were red.

The additional materials required were the same as for Experiment 1. The interruption task was also the same except that participants worked on it for 2 min at a time rather than one.

3.1.4. Procedure

There were two experimenters in the room while each participant was tested. The first experimenter communicated with the participant in Italian while the second dealt with setting up the test materials and observing the participant's behaviour in terms of the number and timing of task attempts, and rule breaks. Other than this the procedure for conducting each condition of the experiment was kept as close to Experiment 1 as possible. One of the differences (due to the repeated measures design) was that all participants worked through the test without interruption the first time they attempted it, and were interrupted during the second attempt.

Between the two conditions, the participant's memory for the task instructions was tested with the free and cued recall procedure used in Experiment 1 and also before the first condition in Experiment 2. After this the first experimenter asked the participant to move away from the table and turn his or her back while the second experimenter laid out the parallel form of the task. The first experimenter told the participants that she would like them to do the test again with the slightly different materials, while following the same rules. One change to the procedure of Experiment 1 (for the interrupted condition) was that during the interruption, the second experimenter put the task materials back to the positions they had been in when the test began. This ensured that there was no spatial cue to tell the participant what they were working on prior to the interruption—they had to rely on their memory. At the end of the test, the participant's memory for the instructions was tested again using the free and cued recall procedure.

3.2. Results

Number of tasks attempted: In the first condition, only one of the patients attempted all four sub-tasks. In contrast, only one of the controls did *not* attempt all four sub-tasks. One patient worked on one task continuously for 10 min. Three of the patients attempted two sub-tasks while the remaining two attempted three. A two-tailed Pearson Chi-Square test showed that there was a highly significant association between participant type and the number of tasks attempted,

$\chi^2(3, N = 21) = 13.821$, $p < 0.01$. When doing the test for the second time, patients still tended to perseverate, often focusing on one task until it was finished. Again only one patient attempted four tasks, and this was not the same patient that had attempted all four in the 1st condition. Three of the patients attempted three sub-tasks and three attempted two. None of the control participants missed out a sub-task, and again there was a highly significant association between participant type and the number of task attempts, $\chi^2(2, N = 21) = 16.8$, $p < 0.001$.

Multitasking efficiency: The main dependent measure of performance on the multitasking test was the average proportion of completed items that were red, across all four sub-tasks. In the Uninterrupted condition, the mean proportion score for control participants on this measure was 47.47% (SD = 17.95%), which is comparable with Experiment 1. The mean for patients was much lower at 10.92% (SD = 6.11%). In the Interrupted condition performance was much the same, with patients completing an average of 13.9% red (SD = 8.97%) and controls completing 48.1% (SD = 13.63%) on average.

A mixed analysis of variance showed a highly significant between-subjects effect, with patients performing more poorly than controls, $F(1, 19) = 33.321$, $p < 0.001$, MSE = 0.035. However, there was no main effect of the within-subjects factor of interruption condition, $F(1, 19) = 0.851$, ns, MSE = 0.003, and no interaction, $F(1, 19) = 0.383$, ns, MSE = 0.003. Therefore the performance of the patients was much worse than that of controls in both conditions, but the interruptions had no effect on the performance of either group (Fig. 1). The partial Eta squared value for the between-subjects factor of Group (patient or control) was 0.637, suggesting a very powerful effect. For the within-subjects factor of condition, the partial Eta squared was 0.042, which according to Clark-Carter (1997) suggests a small effect.

The total proportion of items completed was also examined for the patients and controls. In the Uninterrupted condition, the patients completed 30.14% (SD = 14.57%) and the controls completed 36.71% (SD = 8.26%). In the Interrupted condition, the patients completed 40.71% (SD = 7.78%) and the controls completed

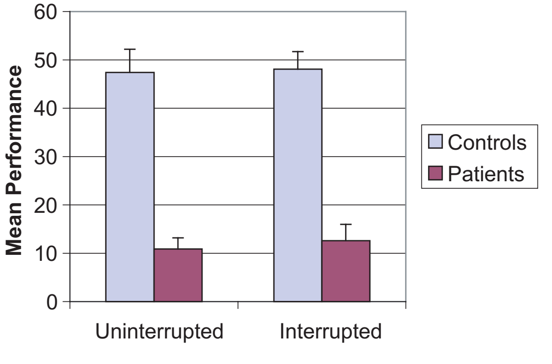

Fig. 1. Average multitasking performance for patients and controls, as measured by the proportion of completed items that were red.

43.07% (SD = 8.23%). A mixed ANOVA revealed that there was a significant main effect of condition, $F(1,19) = 12.892$, $p < 0.01$, MSE = 0.005, but no effect of participant type, $F(1,19) = 1.461$, ns, MSE = 0.013, and no interaction, $F(1,19) = 0.799$, ns, MSE = 0.005. Therefore both patients and controls completed more items of all colours the second time they did the test.

Interruption task performance: As in Experiment 1, performance on the interruption task was measured in terms of the percentage of pictures attempted on which an error was made. All of the participants in Experiment 2 were native Italian speakers. There is an extreme outlier in data; one of the patients appears to have misunderstood the instructions for the task and written down the object names in any order rather than starting at the top of the sheet of pictures and working systematically. His data were therefore removed, leaving a data set ranging from 5.5% to 14.3% for the controls and 11.4% to 26.2% for the patients. The median for the controls was 9.1%, while the median for the patients was 14.8%. As in Experiment 1, participants made errors in their performance of the interruption task suggesting that it did place a demand on their cognitive resources.

Post-interruption behaviour: The number of occasions on which participants returned to the sub-task they had been working on (after the interruption) was lower than in Experiment 1 at 71.43% overall (64.28% for the patients and 75% exactly for the controls). A binomial test (chance = 25%) showed that people returned to the same task significantly more often than any other task ($p < 0.001$). However, a Chi-Square test showed that there was no association between the type of participant and the likelihood of returning to the suspended sub-task following the interruption, χ^2 (1, $N = 42$) = 0.525, ns. Therefore, the patients were not significantly more likely to return to a different sub-task after the interruption than were the controls, even though the percentage of occasions on which they did so was higher.

Rule breaks: Rule breaks in the multitasking test comprised, for example, taking more than one bead out of the box at a time or sealing up the envelopes. These were much more frequent in Experiment 2 than in Experiment 1. The mean number of rule breaks committed by the patients did not change across conditions, at 2.43 (standard deviations were 0.976 in the first condition and 0.535 in the second). The controls made slightly fewer rule breaks in the second condition—the mean was 0.42 (SD = 0.65), down from 0.71 (SD = 0.73) in the first condition. Mann–Whitney tests showed that there were significant differences between the patients and controls in the first condition, $U = 8$, $z = -3.176$; $p < 0.001$, and in the second condition, $U = 2$, $z = -3.696$; $p < 0.001$. Therefore, the patients were much more likely to break the rules of the multitasking test.

Recall of task instructions: Free and cued recall of the task instructions was tested at three time points—before the first condition, between the two conditions and after the second condition. Looking at these data for patients and controls separately (see Table 4), it is clear that the controls achieved much higher scores. Also, *t*-tests (homogeneity of variance not assumed) showed that the difference between patients and controls on free recall was significant at Time 1, $t(19) = -3.859$, $p < 0.01$, Time 2, $t(18.92) = -4.352$, $p < 0.01$, and Time 3, $t(18.89) = -4.442$, $p < 0.01$ (all 2-tailed). The patients were also significantly worse than the controls on the cued recall

Table 4
Free and cued recall of the task instructions—proportion scores at each time point of Experiment 2

	Free recall			Cued recall		
	Time 1	Time 2	Time 3	Time 1	Time 2	Time 3
Patients	0.314	0.329	0.357	0.657	0.815	0.836
Mean (SD)	(0.118)	(0.856)	(0.120)	(0.178)	(0.148)	(0.124)
Controls	0.554	0.593	0.668	0.824	0.967	0.981
Mean (SD)	(0.141)	(0.192)	(0.211)	(0.151)	(0.057)	(0.041)

questions at all three time points—Time 1, $t(19) = -2.246$, $p < 0.05$, Time 2, $t(6.897) = -2.606$, $p < 0.01$, and Time 3, $t(6.66) = -3.025$, $p < 0.01$ (all 2 tailed).

It could be argued that the difference between patients and controls on the multitasking test is simply due to the controls understanding and remembering the instructions better. Therefore an analysis of co-variance was conducted with free and cued recall performance after each condition entered as the co-variates for that condition. With this source of variance partialled out, there was still a significant difference between the patients and the controls in both the uninterrupted condition, $F(1,17) = 6.267$, $p < 0.05$, $\text{MSE} = 0.014$, and the interrupted condition, $F(1,17) = 7.395$, $p < 0.01$, $\text{MSE} = 0.013$.

Prospective memory: In the uninterrupted condition, three of the patients forgot to say "cambio" whenever they switched tasks, two always remembered, one forgot 25% of the time and the 7th did not switch tasks at all. For the controls, five always forgot, seven always remembered and two remembered some of the time. In the interrupted condition, two of the patients always forgot, two always remembered, the other three remembering some of the time. The controls did much better than in Condition 1 however, with nobody forgetting all the time, eight remembering all the time, three people forgetting 33% of the time and the remainder on one or two occasions.

The average rate of prospective memory failure among patients in the first condition was 0.541 (but $\text{SD} = 0.51$) while it was 0.399 ($\text{SD} = 0.476$) for the controls. In the second condition, it was 0.433 ($\text{SD} = 0.426$) for the patients but had fallen to 0.113 ($\text{SD} = 0.145$) for the controls. Mann–Whitney tests showed that the difference was not significant for the first condition, $U = 35$, $z = -0.628$, ns, but was significant for the second condition, $U = 25$, $z = -1.863$, $p < 0.05$ (both one tailed). So, controls managed to improve their prospective memory performance the second time they did the test but patients did not.

3.3. Discussion

The main finding of Experiment 2 was that dysexecutive patients were clearly impaired on the multitasking test relative to matched controls. This was true even when the variance associated with memory for the test instructions was partialled out. This result is in line with several studies in the neuropsychological literature that have found multitasking deficits in patients (Bisiacchi et al., 1998; Burgess et al., 1998;

Burgess et al., 2000; Crépeau et al., 1996; Goldstein et al., 1993; Shallice & Burgess, 1991). This result confirms that the multitasking test that we adopted shows at least the same patterns of performance impairments with such patients as has been reported in the literature.

The main problem patients had was that they tended to perseverate, working for so long on one or two tasks that they ran out of time before they had attempted them all. This tendency has also been observed in the other multitasking studies reported in the literature—for example, Shallice and Burgess (1991) found that patients tended to spend too long on individual sub-tasks (see also Cockburn, 1995). The multitasking test was designed so that failure to switch tasks (i.e. to multitask) would be heavily penalised. In the telephone and envelopes tasks, participants can pick out the red items directly, but they have to come to that realisation by themselves. This was similar to the Strategy Application Test of Levine et al. (1998), where certain high value items were circled. Levine et al. found that patients with focal frontal lesions performed very poorly on this test, seemingly failing to realise that they should complete all the high value items before going on to the others. This lack of insight could also be seen in the patients on the telephone and envelopes tasks. The Lego™ and beads tasks had to be completed in a certain order, but more of the red items were clustered at the beginning, so that these tasks provide diminishing returns the longer participants work on them. The revised Strategy Application Test of Levine, Dawson, Boutet, Schwartz, and Stuss (2000) was designed in a similar way, in that the items on each sub-task got longer as it went on but were only worth the same amount of points all the way through. Levine et al. measured performance by the proportion of completed items that were brief, and found that patients with moderate to severe Traumatic Brain Injury scored less well on the test than did mild TBI or control groups. In a similar way, patients in the present study tended to end up with very low proportions of red items in the Lego™ and beads tasks, because they worked on them for too long.

The other major finding was that even for the patients, there was no disruptive effect of interruptions on performance. It might be argued that patient performance was so poor in the uninterrupted condition that the interruptions could not have made it any worse. Although the patient performance was very low in the uninterrupted condition, it was above floor levels for four patients, and in the interrupted condition none of the patients performed at floor. Of the four patients whose performance had room to deteriorate the second time they did the test, this only happened for one of them. Two of these patients improved and one stayed almost exactly the same. The three patients who had performed at floor level in the uninterrupted condition all improved in the interrupted condition. Therefore there is no evidence that the interruptions were responsible for disruption to patients' multitasking performance. The performance of the control group remained essentially the same in the interrupted condition—a disruptive effect of interruptions was not expected for them based on the evidence of Experiment 1. Post-interruption behaviour was largely the same as in Experiment 1, although the proportion of times that participants returned to the interrupted sub-task was slightly lower at 71.43% compared to 88% (see Section 4).

Overall, patients performed more poorly in terms of multitasking efficiency, recall of the instructions, prospective memory and rule breaks, but they showed the same tendency as the controls to return to the interrupted sub-task after the interruptions. Also, like the controls, they did not appear to find that the interruptions interfered with on-going task performance. While the cognitive processes involved in multitasking are impaired in these patients, there is no evidence that those required for dealing with a brief interruption, and then returning to the on-going task have been damaged.

4. General discussion

Experiment 1 found no effect of interruptions on a test of multitasking with healthy adult participants, while Experiment 2 found that patients were impaired (but above floor) on the test, but that interruptions did not make their performance worse. These results are consistent with previous findings that people who have suffered brain damage, particularly to the frontal lobes, can have difficulty in multitasking (Burgess, 2000). The results are inconsistent with previous findings that interruptions are disruptive to performance of on-going complex tasks (Edwards & Gronlund, 1998; Eyrolle & Cellier, 2000; Speier et al., 1999). However the cognitive psychology literature on interruptions has provided mixed results, with at least one study finding no disruption to on-going task performance (Zijlstra et al., 1999) and others finding that only certain manipulations produced such an effect (Gillie & Broadbent, 1989; Speier et al., 1999). In the present experiments, one main dependent measure was accuracy in terms of the proportion of completed items that were red. In many of the studies that reported a disruptive effect, the disruption was seen in measures of timing rather than accuracy (Eyrolle & Cellier, 2000; Gillie & Broadbent, 1989; Trafton et al., 2003). Speier et al. found some effect on accuracy but timing was more sensitive to their manipulations. It is possible therefore that timing measures are more sensitive to the impact of interruptions, and that this will be seen more clearly in tasks that take place over short time periods. However, this reinforces the view that the effects of interruptions are quite subtle and merit further study.

It is possible that the characteristics of either the interruption task, the multitasking test or both could be changed in ways that would make a disruptive effect more likely. For example, it would be possible to increase the complexity of the on-going multitasking test and investigate whether interruptions were then disruptive (e.g. Speier et al., 1999). However, this would likely decimate patients' performance completely even without interruption. Sub-tasks that are more internally-driven could be chosen in future experiments, which might be more vulnerable to interruption [1] than the stimulus-driven sub-tasks used here (and in most of the previous neuropsychological literature on multitasking). The interruption task itself could

[1] Thanks are due to Bernhard Hommel for this suggestion.

be made more complex (e.g. Gillie & Broadbent, 1989). However, Zijlstra et al. (1999) found no effect of manipulating the complexity of the interruption task (although their on-going task was in no way similar to a multitasking situation). In the present experiments, the unexpected interruption task was chosen to reduce what has been termed the interruption lag (Altmann & Trafton, 2002), rather than for being overly complex. However, there may still have been sufficient time for participants to employ a strategy to maintain their performance on the interruption task (e.g. Trafton et al., 2003). As the interruption was unexpected, this could suggest that people are already quite skilled in dealing with interruptions, which after all occur frequently in everyday life.

Manly et al. (2002) demonstrated that the multitasking performance of their patient group was improved by providing them with periodic tones, which had been explicitly associated with a re-evaluation of overall goals in the instructions for the test. These authors suggest that the stimulus of a tone causes attention to break away from the sub-task at hand momentarily, which provides a time-window in which the participant is more likely to re-evaluate their strategy. According to this account, we might have seen that the interruptions in our task were actually beneficial in breaking the attention of patients from the sub-task they were attempting, and providing an opportunity for this re-evaluation to occur. However, we engaged the attention of our participants with another task as quickly as possible, and we had not instructed them to use the interruptions as an opportunity to consider their goals, as had Manly et al. From a rehabilitation point of view, the finding that dysexecutive patients were able to cope with interruptions with no further disruption to performance is encouraging. Manly et al. have shown how one type of interruption could even be turned into an advantage. This is quite a contrast to the idea that interruptions are inevitably an unwelcome disruption.

As was first observed very clearly in Experiment 1, there is a tendency for people to return to the suspended sub-task after the interruption, rather than changing to a new one. This is in line with what Smith et al. (1997) found in their observational study of secretarial office administration. They referred to it as "prioritisation of suspended tasks", and argued that it was a planning heuristic. Also, Burgess et al. (2000) identified planning as one of the cognitive constructs that supports multitasking. Therefore people may have quite deliberately returned to the task they had been working on in order to keep following their immediate plans, and minimise the disruptive effect of the interruption. It would have been easy for participants to remember which task they had been working on in Experiment 1, not only because the interruption was only a minute long, but also because the interrupted sub-task would normally be positioned in such a way as to indicate that it was "in progress". Participants often moved the materials for the sub-task they were working on into the middle of the table. Therefore if they had lost track of what they were doing, there would be a salient cue to remind them. Another explanation for the post-interruption behaviour is the idea that a "tension" in the cognitive system is created by unfinished tasks (Lewin, 1951; Zeigarnik, 1938). Ovsiankina (1928) demonstrated that people tend to return to tasks that are unfinished, even when not required to do so by the experimenter.

In Experiment 2 the proportion of occasions on which the participants returned to the suspended sub-task was lower than in Experiment 1. The reason for this could be that the materials were returned to their starting positions during the interruption, so there were fewer external cues to remind participants what they had been doing. It was not the case that the patients in Experiment 2 were more likely than controls to choose a task at random to return to after the interruption. This could be seen as more consistent with the idea of an automatic "tension" being created by uncompleted tasks than the idea that people have a deliberately thought out strategy to pick up where they left off. Patients were clearly having trouble applying efficient strategies in the multitasking test, but could still have felt inclined to go back to the same task because of its prominence in memory (Zeigarnik, 1938). However, the likelihood is that both automatic inclination and deliberate strategy use account for the high percentage of occasions on which participants returned to the interrupted sub-task.

In conclusion, our results suggest that the effect of interruptions on multitasking is not necessarily as devastating as popular wisdom might suggest, and that people may often be quite good at coping with brief interruptions while multitasking. Even a sample of brain-damaged patients (who showed a clear impairment in the ability to cope with the multitasking test) was able to deal with being interrupted, working on a new task for 2 min and then returning to the test with no further disruption to performance. This might suggest that, again contrary to what might be a popular assumption, the ability to cope with multitasking comprises a rather different demand on the cognitive system than does the requirement to cope with an externally imposed interruption.

Acknowledgements

Experiment 2 was supported by Study Visit Grants to the first author from the Experimental Psychology Society and the British Psychological Society.

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