



High functioning children with autism spectrum disorder: A novel test of multitasking

Rachael Mackinlay^{a,*}, Tony Charman^a, Annette Karmiloff-Smith^b

^a Behavioural and Brain Sciences Unit, Institute of Child Health, University College London, UK

^b Neurocognitive Development Unit, Institute of Child Health, University College London, UK

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Abstract

High functioning children with a diagnosis of autism or Asperger's syndrome (HF-ASD) often experience difficulties organising goal-directed actions in their day-to-day lives, requiring support to schedule daily activities. This study aimed to capture these everyday difficulties experimentally using multitasking, a methodology that taps into the cognitive processes necessary for successful goal-directed activities in everyday life. We investigated multitasking in children with HF-ASD using a novel multitask test, the Battersea Multitask Paradigm. Thirty boys participated in the study, 14 with HF-ASD and 16 typically developing controls, matched for age and IQ. Group differences in multitasking were observed. Participants with HF-ASD were less efficient at planning, attempted fewer tasks, switched inflexibly between tasks and broke performance rules more frequently than controls.

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1. Introduction

"I bet he'll become a rocket scientist, but I'll probably have to dress him and drive him to work."

Mother speaking of her son with high functioning autism, cited in Ozonoff, Dawson, and McPartland (2002, p. 18).

This mother's comment accurately summarizes the paradox faced by many high functioning children with autism spectrum disorder (HF-ASD). By definition, children with *high functioning* autism have normal or above normal intelligence and relatively well developed structural language and cognitive skills (Ozonoff et al., 2002). However, even though some children with HF-ASD achieve milestones such as forming a career or getting a university degree, they con-

tinue to have difficulties with the demands of everyday life and may struggle to live independently as adults (Howlin & Goode, 1998). One of the reasons that individuals with HF-ASD find it hard to live independently is because they have difficulties organising and coordinating everyday activities. Children with HF-ASD are commonly reported to have difficulties with time management, organising the materials necessary to perform an activity and sequencing activities; generally reflecting a deficit in the ability to plan ahead (Ozonoff et al., 2002). This impacts upon day-to-day life: at school children can fall behind in class due to poor time management and difficulties organising their workload, homework is all too often left at school instead of being brought home. At home, activities of daily living such as getting dressed or getting ready for bed take longer to perform, often leading to frustration on all sides (Ozonoff, 1998).

The question arises of how to capture these everyday problems experimentally. A number of studies have investigated executive control processes in children with HF-ASD. This research has consistently identified executive function (EF) impairments in individuals with autism

* Corresponding author. Present address: Department of Psychology, University of Zürich, Attenhoferstrasse 9, CH-8032 Zürich, Switzerland. Fax: +41 1 634 4929.

E-mail address: r.mackinlay@psychologie.unizh.ch (R. Mackinlay).

(Ozonoff, 1998; Pennington & Ozonoff, 1996). The executive profile of children with ASD is one of ‘high level’ difficulties (Hughes, 2001). Executive deficits in ASD are typically more pronounced than those observed in other developmental disorders (Pennington & Ozonoff, 1996) and may occur across a range of domains of EF (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004). Planning and cognitive flexibility stand out as areas of EF that present particular difficulties for individuals with ASD. Children with ASD plan poorly on tasks such as the Tower of Hanoi (TOH) relative to both clinical (e.g., children with Attention Deficit Hyperactivity Disorder and children with Tourette’s syndrome) and typically developing control groups (Hughes, Russell, & Robbins, 1994; Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991). On tests of cognitive flexibility, participants with ASD demonstrate impaired cognitive flexibility (Ozonoff et al., 1991; Ozonoff, Strayer, McMahon, & Filloux, 1994; Prior & Hoffman, 1990; Szatmari, Tuff, Finlayson, & Bartolucci, 1990), engage in highly perseverative and inflexible strategies (Hughes et al., 1994) and show impaired performance when shifting response set (Ozonoff et al., 1994). In comparison, deficits in inhibitory control are less pronounced in ASD, but may depend upon the measure used to assess inhibitory skills. Participants with ASD often perform as well as controls on traditional tests such as the Stroop test (Eskes, Bryson, & McCormick, 1990; Ozonoff & Jensen, 1999; Russell, Jarrold, & Hood, 1999). However, inhibitory dysfunction in ASD has been reported in studies employing different measures such as Go–NoGo paradigms (Geurts et al., 2004; Nyden, Gillberg, Hjelmquist, & Heiman, 1999).

Although it is probable that this profile of executive dysfunction has a significant impact upon the everyday lives of children with HF-ASD and their families, few studies have sought to measure this effect. Executive dysfunction in children and adults with HF-ASD has been shown to correlate significantly with measures of adaptive behaviour (Ozonoff et al., 2004). Performance on the Tower of London task relates to communication symptoms in school age children with autism (Joseph & Tager-Flusberg, 2004). Poor cognitive flexibility may be related to the everyday repetitive behaviours that characterize ASD (Hughes, 2001), however this relationship has not consistently been reported (Joseph & Tager-Flusberg, 2004).

It is possible that so little evidence exists to support relationships between EF and everyday difficulties in ASD because many tests of EF involve planning or solving a single problem within highly structured, clearly defined limits. In contrast, multitask tests assess an individual’s ability to organise and coordinate the performance of *multiple* activities in a more fluid environment which is more representative of everyday life (Burgess, Veitch, Costello, & Shallice, 2000; Shallice & Burgess, 1991).

In a multitask test, the participant is required to perform a number of tasks within a given time period. The tasks are interleaved, meaning that they cannot be performed sequentially. Success is constrained by a set of rules which

typically restrict the order in which tasks can be performed. These time and rule-based constraints emulate practical restrictions placed upon the organisation of multiple activities in everyday life, such as performing an activity at or within a certain time or performing one activity in advance of another. Indeed, multitask tests have a high ‘ecological validity’ as test performance reflects real life difficulties (Alderman, Burgess, Knight, & Henman, 2003; Burgess, Alderman, Evans, Emslie, & Wilson, 1998).

Adult neurological patients with frontal lobe damage can demonstrate significant impairments organising activities in their day-to-day lives. For example, Shallice and Burgess (1991) report a patient who shopped for food sequentially, returning to his car after purchasing each individual item, because coordinating buying multiple items at one time was too challenging. Such patients perform poorly on multitask tests, demonstrating poor time management (i.e., spending too long on one task), failing to attempt all tasks assigned (despite being aware of the requirement to do so), breaking the rules and carrying out subtasks incorrectly (Burgess & Shallice, 1996; Burgess et al., 2000; Shallice & Burgess, 1991).

The key difficulty of these patients is an impaired ability to create and activate delayed intentions (Burgess et al., 2000). In a multitask test, multiple intentions (to perform multiple tasks) are created, but the execution of the majority of these intentions must be delayed, as it is not possible to perform all the tasks simultaneously. Moreover, during this delay, attention is focused on another activity (the current task) rather than the ‘to-be-performed’ (delayed) tasks. When an intention is delayed, an ‘intention marker’ must be created. When this marker is subsequently activated, it ‘brings to mind’ the intended action and switches the focus of attention to performing the intended task. These processes of marker formation, activation, and intention execution are believed to be impaired in adult frontal lobe patients who perform poorly on multitask tests and in their everyday lives (Burgess, 2000; Burgess et al., 2000).

Recent investigations into the cognitive processes involved in multitasking have placed the organisation of prospective actions firmly within the context of the executive control of behaviour (Burgess et al., 2000; Kliegel, Martin, McDaniel, & Einstein, 2002). The ability to create and activate delayed intentions has been defined as prospective memory, PM (Burgess et al., 2000; Einstein & McDaniel, 1996; Ellis, 1996). Successful prospective remembering is influenced by retrospective mnemonic processes and various executive functions (Burgess et al., 2000; Kliegel et al., 2002; Shallice & Burgess, 1996). Retrospective memory is important for storing the content of an intended action. We not only need to remember that we intend to do something, we must also remember what it was that we intended to do. Planning is the EF most involved in the creation of delayed intentions, and the success with which an intention is executed is influenced by the quality of the plan through which it was set up (Gollwitzer, 1999). Switching attention from a current task to the intended task requires

inhibiting attention to the current task and shifting attention to the intended task, thus involving executive functions such as inhibitory control and cognitive flexibility (Kliegel et al., 2002). Each of these executive functions has been identified as dysfunctional in HF-ASD, providing a strong cognitive basis for investigating multitasking in this group.

Parallels can be drawn between the everyday organisation difficulties reported in adult patients with frontal lobe damage and the problems children with HF-ASD experience in their daily lives. Indeed, multitasking is strongly associated with the prefrontal cortex, and atypical frontal lobe development has been proposed to play a role in autism (Pennington & Ozonoff, 1996). The frontal lobes are extensively connected to other regions of the brain, and hence are well placed to co-ordinate and sequence complex cognitive activity (e.g., Fuster, 1989, 1998; Stuss & Benson, 1987). The ability to organise multiple activities has been associated with the prefrontal cortex in behavioural studies (Bechara, Tranel, & Damasio, 2000; Burgess, 2000; Eslinger & Damasio, 1985; Fortin, Godbout, & Braun, 2002; Shallice & Burgess, 1991), imaging studies (Burgess, Quayle, & Frith, 2001; Yamadori et al., 1997) and neurophysiological studies (Leynes, Marsh, Hicks, Allen, & Mayhorn, 2003; West, Herndon, & Ross-Munroe, 2000). Regions which have consistently been highlighted include the left ventromedial prefrontal cortex and the right dorsolateral prefrontal cortex (Brodmann areas 8, 9, 46, and especially 10). Roles attributed to these regions include maintenance of intention over delay, switching attention from the current to the intended action, intention retrieval, and intention execution.

Observations that the cognitive and behavioural impairments found in autism resemble those of adult patients with frontal lobe injuries led to the hypothesis that atypical frontal lobe development plays a causal role in autism (e.g., Damasio & Maurer, 1978; Pennington & Ozonoff, 1996; Rogers & Pennington, 1991). There is evidence to support atypical structural and functional frontal lobe development in autism (see Volkmar, Lord, Bailey, Schultz, & Klin, 2004 for a review). Maturation of the frontal cortex may be delayed in autism (Zilbovicius et al., 2004). Increased white matter in the whole brain has been reported in infants and toddlers with autism (Courchesne, 2002), and it has been suggested that this reduces overall functional integration and connectivity (Horwitz, Rumsey, Grady, & Rapoport, 1988). Reduced dopaminergic activity (Ernst, Zametkin, Matochik, Pascualvaca, & Cohen, 1997) and increased levels of serotonin (Chugani et al., 1997) have also been reported in the prefrontal cortex of individuals with autism. The dorsomedial prefrontal cortex may be critical for social cognition, and its disruption may lead to the social impairments observed in autism (Schultz et al., 2000). Likewise the ventromedial prefrontal cortex forms part of the brain system claimed to be specialized in social processing and emotional learning (Dawson, Meltzoff, Osterling, & Rinaldi, 1998; Rolls, 1990; Stone, Baron-Cohen, & Knight, 1998). The dorsolateral prefrontal cortex (DLPFC), in particular,

has been closely linked to multitasking (Burgess et al., 2000); reduced activation in this region has been reported when individuals with autism perform cognitive tasks known to be dependent upon this region (Luna et al., 2002). The reliance of the organisation of multiple activities on the prefrontal cortex, together with evidence supporting the atypical development of this region in autism, provides a sound neuroanatomical basis for investigating multitasking in children with HF-ASD.

In sum, children with ASD have difficulty organising their everyday activities and typically need a lot of support to do this effectively (Ozonoff et al., 2002). Multitasking is an experimental test of everyday organisational skills which has high ecological validity (Burgess et al., 1998) and is dependent upon the functioning of the prefrontal cortex (Burgess et al., 2000, 2001). The cognitive processes underlying multitasking include executive functions, so it would seem to be a good methodology to use to investigate everyday organisational difficulties in children with ASD, which have hitherto rarely been investigated experimentally.

To the best of our knowledge, only one investigation touching on multitasking in ASD has been reported. This was done as part of the validation of a clinical test battery designed to measure executive dysfunction in children: the Behavioural Assessment of the Dysexecutive Syndrome for Children (BADS-C, Emslie, Wilson, Burden, Nimmo-Smith, & Wilson, 2003). A group of children who had been referred for clinical assessment and had a variety of clinical diagnoses, including 13 children with ASD, were compared to typically developing children and children with clinical diagnoses who had not been referred for clinical assessment. As part of the BADS-C, children performed the 'Six Part Test' in which they had to attempt six tasks in 10 min with the order of task performance limited by rules. The general results pointed to performance deficits in children with ASD, but no detailed analyses were carried out.

The aim of the present study was to investigate in depth the presence of multitasking impairments in high functioning children with ASD. We designed a novel paradigm to assess multitasking skills in children with HF-ASD and matched controls. Our paradigm measures several of the cognitive processes contributing to multitasking, enabling us to investigate which aspects of multitasking present particular difficulties for children with HF-ASD.

2. Method

2.1. Participants

Since autism is far more prevalent in males, 30 boys participated in this study, 16 typically developing (TD) boys and 14 boys with HF-ASD. TD participants were recruited from two mainstream schools. Participants with HF-ASD were recruited from two clinical centres specialising in the diagnosis of social communication disorders. All had a current clinical diagnosis of childhood autism ($N=9$) or Asperger's syndrome ($N=5$), according to ICD-10 (WHO, 1993) classi-

fications. Nine of the participants with HF-ASD were taking part in an ongoing prevalence study of autism spectrum disorders (Chandler et al., 2005). In addition to having an ICD-10 (WHO, 1993) clinical diagnosis from experienced clinicians, these nine children also met research criterion for a consensus diagnosis of autism where participants were required to score above algorithm cut off point on two of the following three measures: the Autism Diagnostic Interview (ADI-R; Lord, Rutter, & Le Couteur, 1994), the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), and the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999). Although ADI-R and ADOS assessments were not completed for the remaining five children, these children were recruited from one of the leading diagnostic centres in the United Kingdom and diagnosis was made by an experienced clinical team. Additional inclusion criteria for HF-ASD participants included IQ within the normal range and no co-morbid diagnoses. Written parental consent and informed child assent were obtained for each participant prior to assessment. The groups were well matched for chronological age: TD mean = 11 years 11 months ($SD = 6.36$) and HF-ASD mean = 12 years 0 months ($SD = 8.89$).

2.2. Materials

2.2.1. Battersea Multitask Paradigm

The Battersea Multitask Paradigm (BMP) is a children's multitask test that we designed following the principles of the Greenwich Multitask Test for adults (Burgess et al., 2000). The BMP consists of three interleaved but very simple tasks, which children must perform in a time limit of 3 min, with performance constrained by four rules. The rules ensure that to achieve the most effective performance, children must switch frequently between the tasks, rendering sequential performance ineffective.

The three tasks are bead sorting, counter sorting, and caterpillar colouring (Fig. 1). In each task, the child must sort or colour yellow and blue items (beads, counters, caterpillar

circles) to fill a 'cluster' (a pot of beads, a grid of counters or a whole caterpillar). In the beads task, children sort blue and yellow wooden beads (1.5-cm diameter, 150 of each colour) from a large box into eight smaller transparent containers embedded in a wooden tray: 2 small, 4 medium, and 2 large. Half the containers (some of each size) are marked for blue beads and half for yellow beads. In the caterpillar task, children use crayons to colour parts of blue or yellow caterpillars presented on an A3 sheet of paper. Each caterpillar is constructed of circles (2-cm diameter) with one coloured circle representing the 'head' and indicating which colour the 'body' circles should be. There are 12 caterpillars of varying length: 4 short, 6 medium, and 2 long, half to be coloured yellow (some of each length) and half blue. In the counters task, children sort flat blue and yellow counters (1.5-cm diameter, 150 of each colour) from a large tub onto 10 grids of varying size: 4 small, 4 medium, and 2 large. Half the grids are marked for yellow counters (some of each size) and half for blue.

The tasks must be performed in a total time limit of 3 min, displayed visually to the child by a giant sand timer. Task performance is governed by four rules: (1) try all three games before the sand runs out, (2) yellow items get more points than blue, (3) full clusters get extra points, and (4) items must only be picked up or coloured one-by-one. The object of the game is to score maximum points without breaking any rules. The optimal way to perform the game is to fill up small clusters of yellow items in all three tasks; this requires moving flexibly between tasks.

To measure the cognitive processes underlying multitasking, Burgess and colleagues (2000) administered their Greenwich paradigm according to a six-stage invariant behavioural sequence. Each stage generated a dependent variable representing one of the cognitive processes involved, prospective memory, executive functions, and retrospective memory. We adopted this sequence of administration in the present study.

2.2.1.1. Rule learn. The child was introduced to the concept of the multitask game, the experimenter demonstrated each

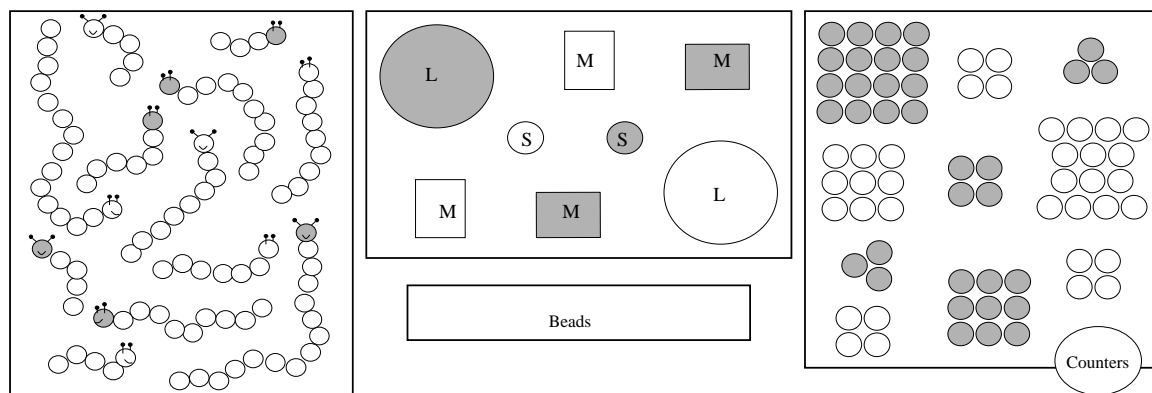


Fig. 1. Birds Eye View of Battersea Multitask Paradigm Test Apparatus. In all tasks, yellow and blue items are sorted to different locations (all blue item locations are shaded). Caterpillars (left) of varying length to be coloured yellow or blue. Bead pots (centre) of varying size (small, medium, and large) to be filled with blue or yellow beads, stored in the box below. Counter grids (right) of varying size to be filled with blue or yellow counters, stored in the pot beside.

task and allowed the child to practice sorting and colouring items one-by-one and filling up clusters. Next the child was shown the giant sand timer and informed that they had only 3 min in which to try all three tasks. At this point the four rules of the paradigm were introduced (see above). It is important to note that tasks and task rules were introduced gently, using demonstrations as well as verbal instructions, to ensure that children were not confused by the simultaneous presentation of multiple verbal instructions. After the rules had been explained and demonstrated, the child was asked to free recall them. The free recall phase ended when the child had correctly recalled all four rules (2 points awarded for each rule free recalled, therefore rule learning criterion score = 8). Finally, to test cued rule recall, the child was asked nine questions about the rules, e.g., ‘how many games must you try?’ (see Appendix A for full list of questions). Free and cued rule learning are summed to form the composite score ‘rule learn.’ Possible range 8–18 points.

2.2.1.2. Plan. Next the child was asked to generate a plan of how they intended to perform the task, gaining as many points as possible and without breaking any rules. Plans were self-paced and recorded verbatim and scored according to the presence or absence of the following elements: plan to try all three tasks (0–3 points, 1 point per task), plan to prioritise yellow items (0–3 points, 1 point per task in which prioritising yellow was planned), and plan to fill up clusters (1 point per task in which filling clusters was planned). The composite score ‘plan’ represents the sum of these scores. Possible range 0–12 points.

2.2.1.3. Perform. There was a time delay of approximately 5–7 min between the introduction of the rules and performance of the task, during this time children had consolidated their knowledge and understanding of the rules and formed a plan of how they would perform the task. Immediately after planning, the child was reminded of the rules and performed the multitask paradigm in the 3-min time limit. Four aspects of performance were scored: (a) ‘Number of tasks attempted’ measuring whether the child attempted to perform all three tasks (1–3 points, 1 point awarded per task attempted), sub-score range = 1–3 points. (b) ‘Strategic performance’ reflecting how well the child applied the rules of the paradigm to gain points; selecting a yellow item first (0–3 points, 1 point for each task on which this was done), selecting significantly more yellow items than blue items (0–3 points, 1 point per task on which this was achieved), selecting smaller, easy to fill clusters first (0–6 points: 2 points for a small cluster, 1 point for a medium cluster, 0 points for large cluster—on each task), prioritising filling a cluster of items (0–3 points, 1 point for each task in which a cluster was filled before moving on to another cluster or task). Sub-score range 1–18 points. (c) ‘Penalty performance’ representing breaking the ‘one-by-one’ rule (–3 to 0 points, subtract 1 point for each task in which this rule is broken) or placement errors made during performance (–3 to 0 points, subtract 1 point for each task

in which a coloured item is incorrectly placed, e.g., blue bead in yellow pot). Sub-score range = –6 to 0 points. (d) ‘Task switch performance’ reflecting how effectively the child switched between the three tasks, categorized as efficient (credited 2 points) or inefficient (debited 2 points). Efficient switchers move fluently between tasks, weighing up the best point-scoring options across as well as within tasks. Inefficient switchers fail to move fluently between tasks, or make multiple switches in a haphazard fashion. The composite score ‘perform’ is the sum of these four aspects of performance. Composite perform score range –3 to 20 points.¹

2.2.1.4. Plan follow. Assessed how well children followed their original plan whilst performing the paradigm. Failure to implement a planned intention was penalized. Plan follow is scored using similar elements to plan: number of tasks planned compared to number of tasks attempted (0–3 points, 1 point per task planned that was subsequently performed), number of tasks in which the child planned to prioritise yellow items compared to number of tasks in which yellow items were prioritised (0–3 points, 1 point per task in which prioritising yellow was planned and subsequently performed), number of tasks in which the child planned to fill up clusters compared to number of tasks in which clusters were filled (0–3 points, 1 point per task in which clusters were planned and subsequently filled), and finally the order in which tasks were planned compared to the order in which they were performed (0–3 points, 1 point for each task where planned order matches performed order). Composite ‘plan follow’ score, possible range 0–12 points.

2.2.1.5. Monitor. After performance the child was asked to tell and show the experimenter what he or she had done and why. Responses were recorded verbatim and scored for the following elements: recount of number of tasks attempted (0–3 points, 1 point per task attempted correctly recounted) and recount of order in which tasks were attempted (0–6 points, 2 points per task recounted in the same order as tasks were performed). Possible range 0–9 points.

2.2.1.6. Rule memory. Finally the child was asked to free recall the four rules of the paradigm (0–8 points, 2 points per rule correctly recalled) and to answer the same cued questions as when learning the rules (0–10 points, see Appendix A for list of questions). Free and cued recall

¹ The lower bound of the possible performance score range is –3, due to worst case scenario. For example, if a child attempted only one task they would score 1 point. If, while performing this task they failed to prioritise yellow, or to fill items etc., no strategic performance points would be awarded. Furthermore, this child could break the one-by-one rule and place coloured items incorrectly, thus being penalized –2 points. Finally, inefficient switching would also be penalised by subtracting 2 points. Therefore summing +1, –2, and –2 gives a lower bound value of –3 points. It should be noted that no children performed the multitask in such an inefficient way.

contribute to the composite score ‘rule memory’—possible range 0–18 points.

These variables tap into the different cognitive processes underlying multitasking. Specifically, ‘rule learn’ and ‘rule memory’ measure the participant’s knowledge of what they are supposed to do, hence retrospective memory. ‘Plan’ is dependent on executive planning skills. Multitask performance variables such as ‘number of tasks attempted’ and ‘task switch’ require both the self-initiated execution of delayed intentions (tapping prospective memory) and executive skills of inhibition and cognitive flexibility. Similarly ‘strategic performance’ and ‘penalty performance’ rely upon executive strategy formation and inhibitory skills respectively. ‘Plan follow’ measures the successful implementation of delayed intentions and as such also represents prospective memory. ‘Monitor’ measures the child’s awareness of what has been achieved and what has still to be achieved and is considered an executive monitoring process. In addition, all these aspects of multitasking are constrained by working memory as participants process multiple components of information in a limited capacity processing space. Given the anecdotal evidence that children with HF-ASD have difficulties organising activities in everyday life and have a profile of executive dysfunction, predictions about their multitasking can be made. Specifically, children with HF-ASD are expected to have difficulties planning compared to controls, and also to demonstrate multitask performance impairments, attempting fewer tasks and switching between tasks less effectively.

2.2.2. Wechsler intelligence scales for children UK 3rd edition

The WISC-III^{UK} (Wechsler, 1992) was used to assess general intellectual ability. Twenty-one participants were tested using a short form of the WISC-III^{UK} in which scores from two verbal sub tests (arithmetic and similarities) and two performance sub tests (block design and picture completion) were prorated to give Full Scale, Verbal and Performance IQ estimates (following Kaufman, Kaufman, Balgopal, & McLean, 1996). Nine children with HF-ASD had been assessed on the full WISC-III^{UK} within the last 12 months, so rather than repeat this assessment their previous scores were used.

2.2.3. Behaviour rating inventory of executive function

Parents of HF-ASD children also completed the BRIEF, an 86-item questionnaire designed to assess EF behaviours in everyday environments (Gioia, Isquith, Guy, & Kenworthy, 2000). The BRIEF yields eight subscales representing domains of executive functioning: inhibit, shift, emotional control, initiate, working memory, plan/organise, organisation of materials and monitor (for further information, see Gioia et al., 2000). Each subscale is reported as a *T* score, with a mean of 50 and a standard deviation (*SD*) of 10. *T* scores at or above 65 are considered as having potential clinical significance. The BRIEF profile of children with HF-ASD is one of elevated scores on all subscales, particu-

larly the shift subscale which measures cognitive flexibility (Gioia, Isquith, Kenworthy, & Barton, 2002). We used the BRIEF: (a) to investigate whether any multitasking deficits observed in children with HF-ASD were also reflected in their everyday environments and anticipated elevated scores and (b) to explore the relationship between specific multitask variables and some BRIEF subscales.

3. Results

The groups were well matched for measures of IQ. Full Scale: HF-ASD mean = 105.6 (*SD* = 12.9), TD mean = 109.1 (*SD* = 12.9). Verbal: HF-ASD mean = 105.8 (*SD* = 17.4), TD mean = 110.2 (*SD* = 16.4). Performance: HF-ASD mean = 104.8 (*SD* = 11.8), TD mean = 105.4 (*SD* = 11.2). One-way analyses of variance revealed no significant differences between the groups on any of these measures.

The BMP generates six composite variables. Group mean scores and standard deviations for each of these variables are detailed in Table 1. Group comparisons were analysed using non parametric Mann–Whitney *U* tests, except for the *plan follow* variable where Analysis of Covariance (ANCOVA) was used to co-vary for the effect of planning. Participants in both groups were equally able to learn and remember the rules of the multitask paradigm, as indicated by the mean scores in Table 1. No significant differences were observed for *rule learn* ($z = -0.90$, ns) or *rule memory* ($z = -1.86$, ns). There was a significant group difference in terms of *planning* how to perform the BMP ($z = -2.93$, $p = .01$); participants with HF-ASD produced less complex plans than TD controls. This difference did not transfer to plan implementation as no group differences in *plan follow* were observed. Note that as the plan follow variable represents the extent to which a participant enacted their original plan, it is yoked to the planning score. Hence group comparisons of plan following are considered after co-varying for the effect of planning group differences in planning (ANCOVA): $F(1, 27) = 2.86$, ns; estimated marginal means HF-ASD mean = 9.48 (standard error, SE = .46), TD mean = 9.70 (SE = .42). These results indicate that despite the seemingly large group differences in the means for plan following, children in both groups were equally able to implement the plan they had formed. Children with HF-ASD performed the multitask paradigm less effectively than

Table 1
Means and standard deviations of HF-ASD and TD groups on key multitask variables and statistical comparisons

Variable (score range)	HF-ASD	TD-control
Rule learn (0–18)	16.86 (1.23)	17.31 (0.7)
Plan (0–12)	8.21 (3.09)	10.81 (1.47)**
Perform (0–20)	12.71 (5.61)	16.62 (3.22)*
Plan follow (0–12)	6.86 (3.18)	10.00 (1.41)
Monitor (0–9)	7.93 (2.05)	9.00 (0.00)
Rule memory (0–18)	15.42 (2.47)	16.87 (1.02)

* Significant at $p = .05$ level.

** Significant at $p = .01$ level.

TD controls ($z = -2.11, p = .03$). Both groups scored well on the *recount* measure, see Table 1. The TD control group scored at ceiling and although the HF-ASD group achieved somewhat lower scores, this difference was not significant ($z = -1.83, ns$).

The multitask variable *perform* is a composite score and we speculated that an examination of the sub-scores contributing to this composite might illuminate which aspects of multitask performance present difficulties for children with HF-ASD. In terms of: (a) The ‘number of tasks attempted’—three children with HF-ASD failed to perform all three tasks (mean = 2.71, $SD = 0.61$) compared to controls who invariably attempted all three tasks (mean = 3.00, $SD = 0.00$). This difference narrowly missed being significant: Mann–Whitney $U, z = -1.92, p = .055$. (b) The ‘strategic performance’ score reflects how well children applied the rules of the paradigm to gain points during performance. No significant group differences were observed for this measure: HF-ASD mean = 13.28 ($SD = 4.03$), TD mean = 15.37, ($SD = 2.27$), Mann–Whitney $U, z = -1.44, ns$. (c) Scores for ‘penalty performance’ indicate that only one child in each group made a placement error. However, 7 of 14 children with HF-ASD broke the rules of the paradigm compared to 2 of 16 TD participants. Fisher’s exact test was used to calculate group differences in task switching as values in one cell were less than five and this difference was significant, $p = .032$. (d) The ‘task switch performance’ score measures the effectiveness with which participants switch fluently between tasks. The most effective way to perform the interleaved tasks of the BMP is to weigh up performance options across tasks (i.e., to identify the smallest yellow items to fill in all three tasks). Therefore, moving sequentially from task 1–2–3 only represents an ineffective performance strategy, and participants who employ this strategy are penalized, despite having attempted all three tasks. We hypothesized that children in the HF-ASD group would switch between tasks less efficiently than children in the TD control group and this was supported by the pattern of our results: 6 children with HF-ASD (43%) adopted an inefficient switch strategy, compared to only 2 TD control children (13%). Group differences in task switching were investigated using Fisher’s exact test, results indicate a non-significant trend, $p = .07$.

Parent ratings on the BRIEF were collected for all participants in the HF-ASD sample. Scores for the eight BRIEF subscales, with a mean of 50 and a standard deviation of 10, are reported in Table 2. Scores above 65 are considered within the clinical range (Gioia et al., 2000). Our results support the BRIEF profile identified in previous research (Gioia et al., 2002), of generally elevated subscale scores with a noticeably high score on the ‘shift’ subscale indicative of cognitive inflexibility. We also investigated hypothesized a priori relationships between specific multitask scores and BRIEF subscale scores, as there are theoretical parallels between some of these variables. Five Pearson correlations were conducted, with age in months and Full-scale IQ partialled out. Multitask plan and BRIEF plan/organise both measure

Table 2
BRIEF scores for the HF-ASD group

BRIEF subscale	Mean (SD)
Inhibit	71.78 (9.61)
Shift	77.00 (8.90)
Emotional control	70.21 (7.63)
Initiate	63.14 (9.69)
Working memory	63.93 (8.76)
Plan/organise	64.78 (9.69)
Organisation of materials	60.93 (8.13)
Monitor	69.86 (6.90)

planning skills but did not correlate: $r = -.04, ns$. Multitask perform, multitask switch and BRIEF initiate all measure the ability to independently self-initiate tasks; significant negative relationships were identified between these variables: multitask perform and BRIEF initiate $r = -.59, p = .04$, multitask switch and BRIEF initiate $r = -.64, p = .02$. Multitask switch and BRIEF shift did not correlate significantly $r = -.24, ns$, although both are thought to measure cognitive flexibility. Finally, no relationship was observed for measures of the ability to track goal-oriented behaviour, multitask monitor and BRIEF monitor, $r = -.26, ns$. Despite having a priori theoretical grounds for predicting two of the relationships observed, we interpret these correlations cautiously. This is because when we correct for family-wise error and adopt a more stringent alpha level (Bonferroni method, alpha is corrected for the five relationships investigated, thus is set at $.05/5 = .01$), the two significant correlations we reported between multitask and BRIEF variables fall below the level of statistical significance.

4. Discussion

We observed multitasking deficits in children with HF-ASD compared to TD controls; indicating that children with HF-ASD were less efficient at planning, organising and coordinating the performance of the multiple activities of the BMP. Although not all comparisons involving performance sub-scores reached significance, trends in the data indicate that attempting all tasks, task switching and rule breaking appear to be problematic for children with HF-ASD. Our results correspond with those of one previous study in which children with HF-ASD exhibited impaired performance on a different and sequentially rigid multitask paradigm (Emslie et al., 2003). Moreover, our results extend this previous research as we left the sequence of task performance to be flexibly inferred and we investigated in depth what might underlie impaired multitask performance. Interestingly, multitasking deficits could not be attributed to group differences in participant’s knowledge of the task before them, as children in both groups demonstrated an equivalent ability to learn and retain the rules governing multitask performance.

Group differences in planning were observed: children with HF-ASD provided significantly less strategic plans than TD controls. This finding is in accordance with the

difficulties planning ahead that children with HF-ASD are reported anecdotally to have at home and at school (Ozonoff et al., 2002). Although many studies have reported planning deficits in ASD (e.g., Geurts et al., 2004; Ozonoff et al., 1991), these deficits tend to be on tasks with clearly defined goals such as tower tasks. Our multitask paradigm taps the ability to plan multiple tasks in a complex environment in which the goals are largely self-determined, which is more characteristic of planning in everyday life. On a cautionary note, planning scores in this study were reliant on verbal output, and verbal fluency can be reduced in ASD (Hughes et al., 1994). The possibility that the planning deficits reported here may be due to group differences in the articulation of verbal plans, rather than impaired planning per se, cannot be discounted at this juncture in the absence of an independent measure of verbal fluency.

Participants with HF-ASD switched between subtasks less efficiently than TD controls. In fact, three participants with HF-ASD failed to attempt all three subtasks, whereas all controls managed to fulfil this basic requirement. These three children engaged in the game as enthusiastically as other participants—but failed to attempt all three tasks. Two children (A and B) ran out of time before switching to the third task, and the third (C) became fixated on one task and failed to switch at all. All three were disappointed when asked to stop by the examiner, in fact children B and C protested that they had not yet tried all the tasks. These three children were able to learn the rules of the paradigm as well as other ASD and control participants, and additionally to recall these rules post performance. Therefore, it is difficult to attribute their poor performance cannot to a lack of comprehension of task instructions, or to poor motivation, hence performance difficulties are attributed to an impaired ability to organise the performance of multiple tasks. Providing further support for this interpretation, even those children with HF-ASD who did attempt all tasks switched between them less often and tended to get ‘stuck’ on task. In total, 50% of children with HF-ASD were inflexible switchers. We had expected task switching to be impaired in children with HF-ASD on the basis of their poor cognitive flexibility (Geurts et al., 2004; Ozonoff & Jensen, 1999) and from results of studies indicating their perseveration in switching set (Ozonoff et al., 1991, 2004; Szatmari et al., 1990).

Although very few participants in either group made performance errors, significantly more children with HF-ASD broke the rules than controls. In adult patients with frontal lobe damage, rule breaking in multitasking has been attributed to poor inhibitory control (Shallice & Burgess, 1991). Although not typically associated with HF-ASD, deficits in inhibitory control have been reported in this population (e.g., Geurts et al., 2004; Nyden et al., 1999). It is therefore possible that this could account for the rule breaking observed. The strategic rule use score represents how effectively an individual maximizes performance given the constraints of the situation. No significant group differences in strategic rule use were observed. Although children

with HF-ASD have been reported to have an impaired ability to use high-level, complex rules (Pennington & Ozonoff, 1996), the rules of the BMP were designed to be very simple and the lack of group differences potentially reflects this aim.

The BRIEF scores observed in our clinical sample indicate that the HF-ASD children do indeed have significant difficulties with executive control in their daily lives. The profile of elevated scores across all eight subscales with the ‘shift’ subscale being the most elevated is entirely consistent with profile generated for children with HF-ASD in two other studies (Gioia et al., 2000, 2002). We investigated relationships between BRIEF sub scores and multitask variables hoping to provide further support for the ecological validity of our paradigm. Although two of the relationships we anticipated were observed, we interpret this finding cautiously as the correlation between variables failed to achieve significance using more rigorous statistical criteria. The BRIEF initiate score correlated with both multitask performance and switching; ‘initiate’ measures the ability to begin tasks independently and to generate thoughts and ideas and this could relate to the requirement to independently begin and switch to many tasks during multitask performance. However, many other relationships we had anticipated were not observed; for example, multitask switch was expected to correlate with the BRIEF shift because task switching is thought to rely upon shifting attention from the current to the prospective activity (Kliegel et al., 2002). Likewise, multitask monitor was expected to correlate with BRIEF monitor as these measures both concern the ability to keep track of goal-directed behaviour. Finally, multitask plan and BRIEF plan/organise failed to show any relationship, despite the fact that planning deficits were observed in the multitask paradigm and planning difficulties were apparent in the elevated BRIEF plan/organise subscale score. Other recent studies have failed to find associations between performance on cognitive tasks and ratings of everyday behaviour (e.g., Ozonoff et al., 2004). One potential limiting factor that also applies in the present study is the lack of variability in BRIEF scores, reflecting the fact that the majority of participants with HF-ASD scored clearly in the impaired range. Another possible explanation for this lack of observed differences is that we only obtained BRIEF ratings from parents, when in fact the questionnaire is designed to be completed independently by both parents and teachers. Parent reports may focus less than teachers on skills such as planning and monitoring, in part because parents are likely to do a lot of the day-to-day organising on behalf of their child to simply get things accomplished. These abilities might be more readily assessed in an environment where the child is expected to be more independent, such as school. Investigations using both parent and teacher questionnaires would be necessary to explore this possibility. A second explanation is that BRIEF subscales and multitask variables may measure different aspects of the same ability; for example planning in the multitask paradigm involves planning in complex, less well-defined

situations, whereas the majority of questions in the BRIEF plan/organise subscale refer to planning ahead towards a single goal.

The inclusion of the BRIEF measure enables us to demonstrate that children with HF-ASD who have impaired multitask performance also have difficulties organising and coordinating activities in everyday life. For the most part these results add to the ecological validity of multitasking as a test of real life organisational difficulties. Further, they contribute to the growing practice in autism research of attempting to link performance on experimental paradigms to ratings of behaviour in everyday life (e.g., Dawson et al., 2002; Joseph & Tager-Flusberg, 2004; Ozonoff et al., 2004; Pellicano, Maybery, Durkin, & Maley, 2006).

Although deficits in planning how to perform the multitask paradigm were observed in children with HF-ASD, these same children did not demonstrate difficulty implementing the plans they had formed. Plan following scores, though yoked to planning scores, did not differ significantly between groups. Similarly, no significant group differences on the multitask monitor score were found, indicating that children in both groups were able to monitor their ongoing performance. Both these results are interesting as they provide a possible platform for intervention. If children with HF-ASD can implement the plans they form and monitor the progress of this implementation, perhaps improving initial planning would facilitate subsequent performance. However, as discussed above, planning differences could be due to group differences in verbal fluency. Likewise group comparisons on the monitor measure could be confounded by the measure being too simple, as the TD control group scored at ceiling. The ability to monitor ongoing performance may rely on metacognitive skills, and these may or may not be impaired in individuals with autism (Farrant, Boucher, & Blades, 1999). Future investigations of multitasking in HF-ASD would benefit at least from independent measures of verbal fluency and comprehension, and at best from minimizing verbal demands where possible.

In sum, the results of the present study highlight an overall deficit in multitask performance in children with HF-ASD relative to age, gender and IQ matched controls, replicating and extending limited previous research. Specifically, planning to perform multiple tasks, performing and switching between multiple tasks and inhibiting rule-breaking behaviour have been shown to be challenging for children with HF-ASD. These results are consistent with the cognitive profile of executive dysfunction in autism, which is one of poor planning, cognitive inflexibility and possible inhibitory dysfunction. We interpret these results as experimental evidence that children with HF-ASD have problems in the prospective organisation of actions. We further supported this interpretation with evidence from a parent report measure which shows that children with HF-ASD who perform poorly on our multitask paradigm demonstrate difficulties organising future-oriented activities in their everyday lives, supporting the ecological validity of our novel multitasking paradigm.

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Appendix A

Cued recall questions for rule learning and rule memory (possible correct answers)

How many games are there? (3)

What is special about yellow things? (Worth more points/than blue)

How many of the games should you try? (All/3)

How long do you have to play the games? (3 min/until the sand/time runs out)

Do you think you could finish all of the games before the sand runs out? (No)

When does the game stop? (After 3 min/when the sand/time runs out)

Can you have more than one thing in your hand? (No)

Why should you go as quickly as you can? (Get lots of points/before time runs out/fill things up)

Why should you try to fill up squares and caterpillars and pots? (To get extra/bonus points)

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