Do children with autism use inner speech and visuospatial resources for the service of executive control? Evidence from suppression in dual tasks

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Three experiments used dual-task suppression methodology to study the use of inner speech and visuospatial resources for mediating central executive performance by children with autism (CWA) and group-matched typically developing (TD) controls. Expt 1 revealed that CWA did not recruit inner speech to facilitate arithmetic task-switching performance: there was no effect of articulatory suppression (AS) on completion time for CWA compared to the TD group. Expt 2 revealed that suppression of visuospatial resources disrupted the task-switching performance of both CWA and TD groups. It also confirmed that the task-switching performance of CWA was significantly slowed by visuospatial compared to AS. Expt 3 showed that CWA also did not employ inner speech, compared to visuospatial resources, for implementing planning movements. Overall, compared to the mixture of representations used by the TD group for problem solving, CWA seemed to use visuospatial working memory resources but not inner speech to service executive control.

The ability to use inner speech plays an important role in the executive control of thought and action. The engagement of implicit verbalization for problem solving is especially relevant to determining whether children with autism (CWA) show deficits in tasks assessing executive function. For example, CWA show deficits in inhibitory control tasks such as the Windows task, in which children must point to an empty box in order to receive a reward displayed in an adjacent transparent container (e.g. Hughes & Russell, 1993), and on the Luria hand game, whereby participants need to make a fist when the experimenter points with a finger and vice versa (e.g. Hughes, 1996). These inhibitory control tasks involve the following of arbitrary rules, and it will be easier to control behaviour if one verbalizes the task demands. Russell (1997) argues that CWA are poor at doing so, and a potential weakness in the use of verbal self-reminding to maintain response rules in working memory makes CWA vulnerable to making perseverative errors. However, where a task involves a verbal response, this disrupts the use of inner speech for controlling behaviour, effectively removing benefits that may be
associated with internal verbalization. In these situations, typically developing (TD) children (who would normally recruit inner speech but are prevented from doing so) and CWA (who would not normally recruit inner speech for the service of executive control) appear to perform at similar levels (e.g. Russell, Jarrold, & Hood, 1999). CWA show intact performance on measures of inhibitory control that do not have rules which are arbitrary in nature as these tasks do not require verbal self-reminding for ensuring rule maintenance in working memory (e.g. Biro & Russell, 2001; Russell et al., 1999).

Russell and colleagues proposed that the executive deficits that characterize autism may partly stem from impairments in the recruitment of inner speech to enhance central executive capacities for flexibly attending to and maintaining irregular response rules. There is other evidence raising the possibility that CWA do not spontaneously enlist inner speech for the service of executive control. Consider, for example, how private speech (i.e. self-directed overt talk) becomes condensed and internalized to form inner speech. The typical developmental trajectory shows that the greatest frequency of private speech use occurs between 4 and 6 years of age whereupon covert inner speech becomes frequently used from roughly 7 to 11 years onwards (Winsler & Naglieri, 2003). There is even a positive relationship between executive performance (e.g. visuospatial planning on the Tower of Hanoi (ToH) task) and the progressive internalization of speech with age (e.g. Fernyhough & Fradley, 2005). However, Winsler, Abar, Feder, Schunn, and Rubio (2007) found that whilst the use of overt private speech decreased for TD participants with increasing chronological age (CA), this pattern was not found for CWA. CWA were also more likely to produce erroneous answers to the Wisconsin Card Sort Task when they were silent compared to the silent performance of control children. The TD children when working in silence were, presumably, covertly talking themselves through the rules of the card-sorting task. Interestingly, Winsler et al. noted that CWA were more likely to show correct sorting performance when participants engaged in private speech during the task. Their results suggest that while overt speech for cognitive regulation may be intact in autism, those individuals may experience difficulties in recruiting fully internalized speech for the service of executive control.

Whitehouse, Maybery, and Durkin (2006) were the first to directly examine the use of inner speech by CWA for managing task-switching on an arithmetic list paradigm. Participants had to complete a list of blocked addition equations and a list of alternating equations which required switching between addition and subtraction. The lists were completed silently by themselves and concurrently with a secondary task that required the overt recitation of a familiar sequence (repeatedly saying ‘Monday’). Articulation of a familiar word or phrase is a secondary task often used to tap inner speech resources provided by the phonological loop of working memory (Baddeley, Chincotta, & Adlam, 2001). The underlying logic is that if the secondary task disrupts performance on the primary task relative to a silent output condition, subvocal speech used by the secondary task is inferred to be involved in performance on the primary task. Whitehouse et al. removed the function and equal signs in the equations, thereby eliminating any external cues that may have otherwise guided action control (e.g. 5 1—: 8 1 —). In order to quickly and accurately complete the task, especially the alternating arithmetic list, participants would have to use inner speech to remind themselves of the operation to be performed for each equation. Whitehouse et al. found that while the TD group took significantly longer to complete both the blocked and alternating task when AS was imposed, the suppression of inner speech did not affect the performance of CWA on either task. The lack of an articulatory suppression (AS) effect for CWA alludes to
weaknesses in recruiting inner speech to maintain changing response rules in working memory to assist with the cognitive control of behaviour.

It is important to acknowledge that Whitehouse et al. (2006) reported a range of evidence to suggest that inner speech may be impaired in CWA. They also documented reduced picture superiority and word-length effects amongst CWA. The picture superiority effect refers to the superior recall of pictorial rather than print information in verbal serial recall tasks in typical development. This effect arises because pictorial information is amenable to semantic encoding through both verbal and visuospatial strategies within working memory rather than verbal strategies alone. A reduced effect in CWA fits with the suggestion that inner speech is unavailable for the encoding of pictorial information in autism. The word-length effect refers to the phenomenon whereby it is easier to remember a sequence consisting of short words (e.g. mat, bag, sun) than long words (e.g. university, perpendicular, electricity). Given that the phonological store within Baddeley’s (2001) model of working memory is a passive system, information can be lost from the store over time if it is not continually refreshed with the use of inner speech. Therefore, the faster one rehearses phonological information, the greater the number of items than can be refreshed in, and retrieved from, this store. The finding that TD children and adults show superior recall for words of shorter than longer spoken duration is also taken as evidence for the use of subvocal rehearsal within the phonological loop (e.g. Hitch, Halliday, Dodd, & Littler, 1989). The lack of a pronounced word-length effect in CWA appears to be consistent with the general suggestion that CWA have impairments in the use of inner speech.

However, Williams, Happé, and Jarrold (2008) have put forward evidence challenging Whitehouse et al.’s argument of impaired inner speech in autism. Williams et al. assert that the word-length effect is an ambiguous measure of inner speech use because it may be attributable to the time taken to say words during recall rather than the time taken to refresh words during rehearsal. Specifically, the more time it takes to vocalize a word during recall, the longer other information within the recall list must be maintained within the phonological store, and the more vulnerable other items are to decay. Given the ambiguities of interpreting the word-length effect, they investigated whether CWA demonstrate the phonological similarity effect, which cannot be as easily confounded by the duration of spoken output (items are matched for syllable length). This is another phenomenon which occurs in typical development whereby immediate serial recall is worse if words sound similar to each other than if they do not (Baddeley, 2003). Williams et al. examined the immediate serial recall of picture items that were visually similar (e.g. pen, knife, brush, and bone), phonologically similar (e.g. cat, hat, bat, and tap), or those that were visually and phonologically dissimilar. Both CWA and control participants (diagnosed with generalized learning disability), with verbal mental ages (VMAs) over 7 years, demonstrated poorer recall of phonologically similar items than control stimuli. These findings do not fit the general conclusions of Whitehouse et al. (2006) to the extent that if CWA show inner speech impairments per se, the performance cost for the recall of phonologically similar items would not have been significant for these participants. Williams et al. also found that, for children with VMAs below 7 years, representation of pictorial information was based on visuospatial properties: all groups showed significantly poorer recall performance of visuospatially confusable items compared to control stimuli. A switch from visual to verbal representation appears to underpin short-term memory span in CWA and control participants, and the transition in representational format encoding for item recall is associated with developmental level.
It is possible that both Whitehouse et al. (2006) and Williams et al. (2008) are correct, but their findings address different qualities of inner speech use. Williams et al.'s work indicates that CWA show intact capabilities to use inner speech for short-term maintenance of verbal information within the phonological loop component of working memory. However, an important aspect of Whitehouse et al.'s work is that it invites us to consider how inner speech may be more than a temporary memory or rehearsal device, in that it may also support central executive contributions to the retrieval and activation of task operations (see also Emerson & Miyake, 2003). It is possible that the quality of inner speech use in autism may be uneven: intact recruitment of articulatory rehearsal for verbal memory span and potential weaknesses in the recruitment of covert verbal rehearsal for supporting central executive processes (e.g. control and switching of attention, planning, inhibition). This possibility comports with evidence provided by Joseph, Steele, Meyer, and Tager-Flusberg (2005). Joseph et al. examined the extent to which CWA were deficient in the use of verbal mediation strategies for executive working memory via the self-ordered pointing test (SOPT). In one version of the SOPT, a set of pictures of familiar concrete objects were arranged in a grid; the items were presented in a different spatial composition on each trial and participants were required to point to a different picture each time. The task requires the central executive ability to generate a sequence of novel responses and monitor actions already made and retained in working memory with choices yet to be made. Joseph et al. found that, in contrast to TD children, the SOPT performance of CWA was poor when the task involved concrete namable items and, further, displayed no significant association with language ability. Importantly, though, CWA performed equivalently to the TD group on a verbal span task. The results indicate that although covert verbal rehearsal skills within the phonological loop are not impaired in autism, children with the disorder do not appear to recruit internal verbal representations for assistance with the self-regulation and monitoring of a sequence of actions by the central executive. Consequently, given that inner speech also contributes to supporting executive control over setting up, maintaining and operating task-specific programmes (e.g. Baddeley et al., 2001), and that CWA do not show any effect of AS on task-switching performance (Whitehouse et al., 2006), the study of suppression effects in a dual-task paradigm may be especially sensitive to revealing potential limitations of the self-regulatory qualities provided by inner speech function in autism.

Whitehouse et al. (2006) did not address the question of how CWA managed to flexibly switch attention between addition and subtraction without using covert inner speech to service executive control. They speculate that CWA may have completed the alternating arithmetic task by recruiting visuospatial representations as a means of planning. There is research suggesting visuospatial representations may be available for problem solving in autism. Joseph et al. (2005) found that CWA did as well as control participants on the SOPT when it involved abstract patterns that could not be described with verbal labels. For the CWA group, there was also a significant correlation between non-verbal SOPT performance and general visuospatial recognition memory. Silk et al. (2006) also found that response times and accuracy of individuals with autism spectrum disorder on mental rotation (a task that is based on the functions of the visuospatial sketchpad component of working memory) did not differ significantly from the performance of TD individuals. Functional MRI evidence indicated that the superior and inferior parietal regions underlying visuospatial processing were also activated in both groups when participants carried out the mental rotation task. It is important then to examine whether CWA experience difficulties in recruiting inner speech for the service
of executive control, and whether they may be able to use intact visuospatial resources to mediate cognitive regulation. Whitehouse et al. recommended studying the effects of visuospatial suppression (VSS) in a dual-task methodology to determine the strategies used by CWA for the facilitation of executive tasks. The present investigation threads their suggestion through three experiments.

The first aim of our research was to replicate certain findings of Whitehouse et al. (2006) to determine whether CWA are impaired in their recruitment of inner speech for task-switching on the arithmetic list paradigm. Expt 1 examined whether AS affected the arithmetic task-switching performance of CWA and TD controls. The second aim of our work was to assess whether visuospatial resources in working memory are enlisted for executive control by CWA. Expt 2 investigated the effect of a concurrent VSS task on participants' arithmetic task-switching performance. The final aim was to assess whether the diminished recruitment of inner speech in CWA generalizes to central executive skills beyond attentional switching. Expt 3 explored the contribution of inner speech and visuospatial representations to executive performance on the ToH planning task. Overall, these experiments sought to clarify the extent to which CWA recruit verbal and/or visuospatial representations for the service of executive control.

EXPERIMENT 1

The arithmetic task-switching paradigm employed by Whitehouse et al. (2006) was utilized to investigate inner speech use in CWA. Based on their research, two predictions were made. It was hypothesized that for both CWA and TD control participants, the completion of the alternating arithmetic task would take significantly longer than a blocked addition task because of the attentional switching demands of the former task. It was also predicted that the added imposition of AS would lead to a detriment in overall task completion time for TD participants because of the interruption to inner speech. However, if CWA demonstrate impairment in the use of inner speech, they should be unaffected in task completion time with the added imposition of AS, compared to baseline silent performance.

Method

Participants

Participants in the CWA group were independently diagnosed and confirmed with autism (N = 13) using Diagnostic and statistical manual - 4th ed. criteria (American Psychiatric Association [APA], 1994) by a clinical psychologist, paediatrician, and a speech pathologist. Participants were recruited through specialist mental health units around Wellington in New Zealand. Each participant also had a Gilliam Autism Rating Scale - 2nd ed. (GARS-2) autism index score of greater than or equal to 80 ($M = 97.85$, $SD = 7.86$; range $= 81$ - $109$), which suggests a strong probability of autism (Gilliam, 2005).

VMA for all participants was determined using the Peabody Picture Vocabulary Test - III (PPVT-III; Dunn & Dunn, 1997). The arithmetic subtest of the Wechsler Intelligence Scale for Children - III (WISC-III; Wechsler, 1992) was administered prior to experimental testing to gauge participants' numerical reasoning ability. Raw scores were used to indicate numerical ability (out of 24).
The study also involved TD participants \( (N = 13) \) who were group-matched to the autism participants on CA, VMA and numerical reasoning ability. The control participants were recruited through local primary and secondary schools in Wellington. Based on teacher reports, none of these participants had neurological or developmental difficulties. The CWA and TD participant groups did not differ significantly on CA \( (F(1, 24) = 3.17, \ p > .05) \), VMA \( (F(1, 24) = .01, \ p > .05) \), or numerical ability \( (F(1, 24) = .63, \ p > .05) \). Participant characteristics are reported in Table 1.

### Table 1. Means (\( M \)) and standard deviations (\( SD \)) of chronological age (CA), verbal mental age (VMA) and numerical reasoning for children with autism (CWA), and typically developing (TD) control groups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CWA (( N = 13 ))</th>
<th>TD control (( N = 13 ))</th>
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</thead>
<tbody>
<tr>
<td>CA</td>
<td>10.9</td>
<td>9.4</td>
</tr>
<tr>
<td>VMA</td>
<td>11.5</td>
<td>11.3</td>
</tr>
<tr>
<td>Numerical reasoning</td>
<td>15.54</td>
<td>15.77</td>
</tr>
</tbody>
</table>

### Materials

All participants were invited to complete two arithmetic tasks (blocked addition and alternating addition followed by subtraction), each under two different output conditions (silent and AS). Each task, under each condition, required the completion of a different list of arithmetic equations and, consequently, four different lists were produced. Each list involved the completion of 20 simple arithmetic equations. All function and equals signs were omitted from the equations requiring the participant to add or subtract one from a randomly assigned digit (e.g. 4 1 _). Each list began with a different equation determined at random. The criteria used for the random sequencing of equations were that all the solutions involved a single digit between one and nine and that no two consecutive equations or solutions were the same. A metronome was set to the rate of AS at 60 beat/min to prevent participants from employing inner speech to solve the equations in between the articulation of words. It was also used during the silent condition to control for any noise interference which may otherwise have occurred for the AS condition only. The experimenter used a stopwatch to time the completion of each list of 20 equations in seconds.

### Procedure

All testing with CWA was conducted in a quiet room in the child’s home with their parent or caregiver present. All testing of TD control participants was conducted at the child’s school in a quiet designated space as determined by a teacher. Each session lasted for a maximum of 30 min. A within-subjects design was followed whereby all participants completed each type of arithmetic task (blocked and alternating) under two different output conditions (silent and AS). For the blocked task, participants were asked to complete the entire list as if all the equations were addition. For the alternating task, participants were instructed to complete the list as if the first equation was addition and the second was subtraction and so on. For the silent output condition, participants were asked to silently complete the lists as fast and as accurately as possible. For the AS output condition, participants were required to complete the arithmetic list
as fast and as accurately as possible, while concurrently articulating the days of the week, in order and beginning with ‘Monday’, in time with the metronome. Prior to this, participants were given as much articulation practice as required to ensure that all verbalization was produced in time with the metronome. During the AS output testing conditions, all participants were able to perform the secondary task in time with the metronome and did not need reminders to verbalize to the beat. For all equations, participants were required to supply written answers on the lists provided. All participants began each new condition (silent and AS) with five practice equations to ensure comprehension of the task instructions.

The first experimental conditions completed by the participants were the blocked and alternating task (counterbalanced) under the baseline silent output condition. Subsequently, participants completed the blocked and alternating task (counterbalanced) under the AS output condition. Each arithmetic list was also counterbalanced across conditions and groups using a Latin square (Ozonoff & Strayer, 2001). Following Whitehouse et al. (2006), the time taken to complete each list was used as the principal dependent variable. The experimenter also recorded the number of errors made in each list and Whitehouse et al.’s procedure was used to score errors. For the blocked addition, each error was scored as incorrect because the arithmetic operation was the same for all equations in the list. For the alternating lists, when an error was made it was scored as incorrect but was treated as forming the start of a new alternating sequence. For example, if the error occurred because two consecutive equations were both treated as addition, the second erroneous answer was scored as incorrect. However, the subsequent equation was treated as resulting from a subtraction operation even though it was out of sequence with the original order. This procedure avoids scoring all responses as incorrect simply because they were out of sequence after a single error had been made.

Results

Figure 1 shows the mean completion time performance of CWA and TD groups across the output conditions for both blocked and alternating lists (see left panel). Participants’ task completion time data were submitted to a 2 (group: CWA vs. TD control) × 2 (task: blocked vs. alternating) × 2 (condition: silent vs. AS) ANOVA where task and output condition were within-subject factors. There were significant main effects of task \(F(1, 24) = 44.40, \ p < .001, \ \eta_p^2 = .65\) and condition \(F(1, 24) = 16.85, \ p < .001, \ \eta_p^2 = .41\). However, these effects were qualified by two significant two-way interactions: task × condition \(F(1, 24) = 5.57, \ p < .05, \ \eta_p^2 = .19\) and group × condition \(F(1, 24) = 4.30, \ p < .05, \ \eta_p^2 = .15\).

For the task × condition interaction, a simple main effects analysis indicated that participants took longer to complete the blocked addition task under AS \(M = 75.33; \ SD = 36.73\) compared to the silent output condition \(M = 60.82 s; \ SD = 31.89\); \(F(1, 25) = 6.62, \ p < .05; \ \eta_p^2 = .21\). Participants also took significantly longer to complete the alternating task under AS \(M = 138.59; \ SD = 78.42\) compared to the silent output condition \(M = 102.94; \ SD = 47.38; \ F(1, 25) = 13.42, \ p < .01; \ \eta_p^2 = .35\). However, the latency cost of AS (i.e. difference in completion time between the AS and silent output conditions) was greater for the alternating task \(M = 35.65; \ SD = 49.62\) compared to the blocked task \(M = 14.51; \ SD = 28.76; \ F(1, 25) = 5.33, \ p < .05; \ \eta_p^2 = .18\). Simple main effects analysis to interpret the group × condition interaction
indicated that for CWA, the imposition of AS ($M = 93.22; SD = 15.39$) did not significantly affect completion time compared to performance in the silent condition ($M = 80.81; SD = 12.73; F(1, 12) = 1.88, p > .05$). However, TD participants took longer to complete all tasks under the AS condition ($M = 120.70; SD = 13.71$) compared to the silent condition ($M = 82.95; SD = 7.81$) ($F(1, 12) = 21.20, p < .01; \eta^2_p = .64$).

Further analyses were carried out to explicitly highlight that the TD group, unlike the CWA group, was affected more by the AS imposition when completing the alternating task. Participants’ completion time data for the blocked and alternating tasks were each analysed in separate 2 (group: CWA vs. TD control) $\times$ 2 (condition: silent vs. AS) ANOVAs where output condition was a within-subjects factor. For the blocked task, there was no significant group $\times$ condition interaction ($F(1, 24) = 1.17, p > .05$). However, there was a significant group $\times$ condition interaction for the alternating task ($F(1, 24) = 4.46, p < .05; \eta^2_p = .16$). CWA demonstrated no significant difference in completion time for the alternating task regardless of whether the task was output in silence or with the added imposition of AS ($M_{\text{alternating-silent}} = 98.72, SD = 53.53$ and $M_{\text{alternating-AS}} = 115.11, SD = 74.84$; $t(12) = 1.39, p > .05$). In contrast, the TD group took significantly longer to complete the alternating task with the added imposition of AS ($M_{\text{alternating-silent}} = 107.16, SD = 42.09$ and $M_{\text{alternating-AS}} = 162.07, SD = 77.57$; $t(12) = 3.95, p < .01$).

Error data were also analysed in a corresponding 2 (group) $\times$ 2 (task) $\times$ 2 (condition) ANOVA. There was only a significant main effect of task ($F(1, 24) = 12.18,
There were a greater number of errors made for the alternating arithmetic task could, however, be due to individual differences in factors associated with VMA (and general maturation or numerical reasoning ability). Even though participants in the CWA and TD groups were matched at the group level, at the individual level, variation in language ability could protect CWA from the AS effect. To test this possibility, we examined whether general maturation, VMA, and numerical reasoning ability were associated with latency and accuracy costs of AS for the alternating task (i.e. difference in performance under the AS and silent output conditions) for each group (see Table 2).

Table 2. Bivariate associations involving chronological age, verbal mental age, and numerical reasoning with the latency and accuracy costs of AS for the alternating task for the CWA and TD control groups

<table>
<thead>
<tr>
<th></th>
<th>Latency cost</th>
<th>Accuracy cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CWA</td>
<td>TD control</td>
</tr>
<tr>
<td>CA</td>
<td>-.37</td>
<td>-.29</td>
</tr>
<tr>
<td>VMA</td>
<td>.18</td>
<td>-.60*</td>
</tr>
<tr>
<td>Numerical reasoning</td>
<td>.18</td>
<td>-.59*</td>
</tr>
</tbody>
</table>

*p < .05.

For the TD group, the higher participants’ VMA (and numerical reasoning), the lower the latency cost of AS on their performance on the alternating task. For the CWA group, none of the correlations were significant. For CWA, the lack of significant correlation between verbal ability and executive performance despite functional language skills, alongside the lack of an AS effect on task-switching, highlight a failure to exploit verbal capacities for the service of executive control.

Discussion

A time completion cost between the silent and AS conditions for the alternating task, as demonstrated by the TD control participants, illustrated that the suppression of inner speech compromised task-switching latency. In contrast, for CWA, the imposition of AS did not affect task-switching completion time for the alternating task compared to baseline silent performance. These results replicate Whitehouse et al.’s (2006) findings and indicate that CWA do not spontaneously use inner speech to facilitate task-switching performance. Given that performance on the alternating task in the baseline silent condition was similar between groups and, further, that the CWA group did not employ inner speech for completing the alternating task, the results lead to the suggestion that those participants’ equitable performance on the task across output conditions may have been brought about by non-verbal resources. Indeed, in order to carry out task-switching without latency cost during the imposition of AS, CWA must have had to rely on other representations to maintain the changing arithmetic rules in working memory with some level of speed and accuracy.

Many studies have used dual-task suppression paradigms to support the availability of visuospatial signals for refreshing information in working memory (e.g. Farmer,
The selective balance of signals recruited from verbal and visuospatial representational subsystems in working memory may depend on the nature of the task to be completed, although both components typically contribute to overall cognitive regulation (Kübler, Murphy, Kaufman, Stein, & Garavan, 2003). It seems plausible to suggest that CWA, whilst demonstrating inner speech limitations, may be able to draw upon visuospatial resources for servicing executive control. If so, the imposition of VSS on the alternating arithmetic task, to block support from the visuospatial sketchpad, should affect the task-switching performance of CWA.

**EXPERIMENT 2**

Several dual-task studies with TD participants indicate that non-verbal codes are also implicated in arithmetic operations. For example, Logie, Gilhooly, and Wynn (1994) found that a secondary visuospatial task disrupted operand maintenance on the primary arithmetic task whereby adult participants were shown a series of addends, one at a time, and had to keep a running total (e.g. $13 + 18 + 13 + 21$). They found that AS also disrupted operand maintenance, but the effect was greater when the running addition task was presented in an auditory modality than in a visual one. In a developmental study on progression in strategy use, McKenzie, Bull, and Gray (2003) found that young children (6–7 years) showed a substantial drop in accuracy on mental arithmetic problems (e.g. $4 + 3 + 7$) only upon phonological disruption. However, amongst older children (8–9 years), there was a significant drop in performance (compared to baseline) under both phonological and visuospatial disruption. Older children appear to use a mixture of strategies based on inner speech and visuospatial representations. These dual-task studies show that different codes in working memory (phonological and visuospatial) are activated during mental arithmetic and that variability in the allocation of those representations to solution strategies, broadly or specifically, may also depend on particular task factors. Other related studies on individual differences have further confirmed that visuospatial working memory capacity is positively correlated with children’s performances on a variety of numerical tasks (e.g. Bull, Espy, & Wiebe, 2008; Holmes, Adams, & Hamilton, 2008). On balance, a broad range of literature suggests close connections between non-verbal working memory and arithmetic performance, and such evidence bolsters the possibility that arithmetic task-switching could also draw upon support from the visuospatial sketchpad component of working memory for both CWA and TD groups. Consequently, in Expt 2, participants’ arithmetic task performance was measured under a VSS output condition.

Importantly, whilst the findings of Expt 1 replicate Whitehouse et al.’s (2006) study indicating that CWA do not use inner speech for managing task-switching, we do not assume for Expt 2 that CWA would necessarily have enhanced ability to recruit visuospatial representations, and hence do not expect that VSS would have a greater impact on CWA compared to the TD group. There is evidence of unremarkable visuospatial working memory capacity in autism. Several studies using visual search, mental rotation, and non-verbal self-ordered pointing tasks have found evidence for intact visuospatial working memory processes (e.g. Edgin & Pennington, 2005; Joseph et al., 2005; Ozonoff & Strayer, 2001; Silk et al., 2006). Caron, Mottron, Rainville, and Chouinard (2004) also found that increases on memory load within a visuospatial task (e.g. number of decision points on a route mapping task) have the same level of
detrimental effect for both autism and TD groups. Caron et al. suggest that basic visuospatial working memory processes appear to be relatively preserved in autism, and suggest that popular self-reports of individuals with autism showing enhanced visuospatial ability *per se* might result from implicit comparisons with their substantially impaired language and social cognition skills. Indeed, other researchers have reported evidence of impaired performance by CWA on more complex visuospatial tasks (e.g. Minshew & Goldstein, 2001; Minshew, Luna, & Sweeney, 1999). Research collectively demonstrating an uneven profile of intact and diminished visuospatial working memory in autism is compatible with Williams et al.’s (2008) findings that CWA may be able to perform as well as their TD counterparts in recoding visually presented material into a verbal medium under certain circumstances (e.g. short-term recall). Visuospatial thinking does not appear to be the only defining problem-solving strategy available to individuals with autism. Consequently, we predicted that VSS would result in a higher time cost for the alternating arithmetic task for the CWA and TD groups, and that the impact would be equitable upon the two groups.

**Method**

**Participants**
The participants were the same as those in Expt 1. Each participating family was contacted at least one week after the end of Expt 1 and all families gave informed consent for their child to take part in Expt 2.

**Materials**
All participants were invited to complete blocked addition and alternating arithmetic tasks under a VSS condition. Two new lists of mathematical equations were therefore used. The compilation and completion of each list followed the same procedure described in Expt 1. A plastic board with nine blue blocks attached was used to conduct the secondary VSS task. A metronome was used to control the rate of VSS and was set to the same rhythm as in Expt 1 (60 beat/min). The experimenter used a stopwatch to time the completion of each list of 20 equations in seconds.

**Procedure**
Participant testing was carried out in the same manner as in Expt 1. A within-subjects design was followed whereby all participants completed each type of arithmetic task (blocked and alternating) under a VSS condition. The presentation of the arithmetic tasks was counterbalanced across participants. With respect to VSS, participants first practiced tapping four of the blocks in a specified pattern, in time with the metronome. The pattern (see Figure 2) involved the repetition of a forward tapping movement starting from the top-left block to the bottom-right block and then the top-right block to the bottom-left block (Garden *et al.*, 2002). All participants were given as much practice time as required to produce the sequential tapping in time with the metronome. Participants performed the tapping task outside their visual field and with their non-preferred writing hand. The experimenter observed that, whilst performing the primary task, all participants did not stray from the beat of the metronome in carrying out the secondary sequential tapping task. Performance on the primary arithmetic tasks was timed and scored in the same manner as described in Expt 1.
Results

Using also the silent condition baseline data collected in Expt 1, participants’ completion time for the tasks completed under the VSS condition were submitted to a 2 (group: CWA vs. TD) × 2 (task: blocked vs. alternating) × 2 (condition: silent vs. VS) ANOVA where task and condition were within-subject factors. Analysis revealed only significant main effects of task \( F(1, 24) = 52.51, p < .001, \eta_p^2 = .69 \) and condition \( F(1, 24) = 49.55, p < .001, \eta_p^2 = .67 \). Participants were slower for the alternating task \((M = 133.28; SD = 11.74)\) compared to the blocked task \((M = 85.97; SD = 7.08)\), and participants demonstrated slower performance under the VSS output \((M = 137.37; SD = 11.91)\) compared to the silent condition \((M = 81.88; SD = 7.47)\). The significant group × condition interaction that was found in Expt 1 when the AS output condition was involved, now disappeared when the VSS condition was contrasted \((F(1, 24) = .01, p > .05)\). The imposition of VSS significantly slowed task performance for both participant groups (see right panel in Figure 1). Indeed, compared to silent output performance, CWA took significantly longer to complete both the blocked task \((t(12) = 4.56, p < .01)\) and alternating task \((t(12) = 4.87, p < .01)\) under the VSS condition \((M_{\text{blocked-silent}} = 62.89, SD = 42.44 \text{ vs. } M_{\text{blocked-VSS}} = 110.51, SD = 51.02; M_{\text{alternating-silent}} = 98.72, SD = 53.53 \text{ vs. } M_{\text{alternating-VSS}} = 161.25, SD = 87.45)\). Compared to performance in the silent condition, the TD group also took significantly longer to complete both the blocked task \((t(12) = 4.52, p < .01)\) and alternating task \((t(12) = 4.51, p < .01)\) under the VSS condition \((M_{\text{blocked-silent}} = 58.75, SD = 17.56 \text{ vs. } M_{\text{blocked-VSS}} = 111.72, SD = 45.81; M_{\text{alternating-silent}} = 107.16, SD = 42.09 \text{ vs. } M_{\text{alternating-AS}} = 166.00, SD = 65.08)\).

Error data under the VSS condition compared to the silent condition were analysed in a corresponding 2 × 2 × 2 ANOVA. Analysis revealed only a significant main effect of task \((F(1, 24) = 29.44, p < .001; \eta_p^2 = .55)\). There was a greater mean number of errors made for the alternating task \((M = 1.94; SD = 0.37)\) than the blocked addition task \((M = 0.33; SD = 0.15)\).

The latency results for the alternating task obtained across Expts 1 and 2 are crucial: CWA did not show a performance cost in task-switching during the AS condition (Expt 1), but they did experience a latency cost during the VSS condition (Expt 2).

Figure 2. Pattern of concurrent movement (sequential tapping from locations 1, 2, 3 to 4) that was required during VSS output.
To bring these differences to the fore, we carried out a 2 (group: CWA vs. TD) × 2 (condition: AS vs. VSS) ANOVA on completion times for the alternating task. There was a significant main effect of condition ($F(1, 14) = 6.60, p < .05, \eta^2_p = .22$) that was further qualified by a significant group × condition interaction ($F(1, 24) = 4.70, p < .05, \eta^2_p = .17$). The group × condition interaction was such that the TD group displayed no significant difference in latency performance on the alternating task regardless of output condition ($M_{VSS} = 166.00, SD = 65.07$ and $M_{AS} = 162.07, SD = 77.57; t(12) = .25, p > .05$), but CWA took significantly longer to complete it under the VSS condition ($M = 161.25; SD = 87.45$) compared to the AS condition ($M = 115.11; SD = 74.84; t(12) = 3.88, p < .01$). A similar group × condition ANOVA for the blocked task showed only a significant main effect of condition ($F(1, 24) = 23.80, p < .001; \eta^2_p = .50$). Participants took longer to complete the blocked task during the VSS output ($M = 111.12; SD = 9.51$) compared to the AS output ($M = 75.33; SD = 7.31$).

Discussion

Aside from arithmetic task-switching being also supported by visuospatial working memory resources, the results indicated that VSS in comparison to AS slowed completion time on the blocked arithmetic task. These findings fit with a range of literature showing a close connection between mental arithmetic and visuospatial representations and that the visuospatial sketchpad of working memory can support different aspects of mathematical reasoning (e.g. Bull et al., 2008; McKenzie et al., 2003). Importantly, the findings further revealed that CWA incurred a greater performance cost when completing the alternating list under the VSS condition compared to the AS condition, but participants in the TD group showed no difference in completion time for the alternating task between the two conditions. In that sense, the results of Expt 2 supported our expectation that the imposition of VSS effectively blocked the use of visuospatial working memory resources that would otherwise have been recruited for the service of task-switching by CWA.

A further aspect of the findings was that, as expected, the imposition of the concurrent VSS condition affected task-switching time performance equitably in both groups. The fact that task-switching in the TD group was similarly affected by both AS and VSS output conditions suggests that children typically have multiple strategies available for elaborating upon their problem solving. Our finding that the CWA group was not significantly more disrupted by the VSS output condition compared to the TD group suggests that visuospatial representations should not be regarded as being the only means by which children with the disorder manage problem solving in lieu of limitations in the quality of their inner speech use. If CWA can use inner speech to support performance on particular tasks (e.g. short-term recall; Williams et al., 2008), it is logical that visuospatial thinking would not necessarily be the primary or defining problem-solving strategy available to children with the disorder. Our findings showing no differential dependency upon the visuospatial sketchpad of working memory by the CWA group in the VSS results are also consistent with the broader literature that there is an uneven profile of intact and impaired visuospatial cognition in autism (e.g. Caron et al., 2004; Minshew & Goldstein, 2001). Instead of pointing to an over dependency upon visuospatial resources for servicing central executive control over task-switching, our dual-task suppression results suggest that CWA show an intact ability to use visuospatial representations for supporting arithmetic task-switching. Overall, our findings can be parsimoniously regarded as
evidence for CWA demonstrating impoverished representational elaborations in the context of service to executive control, whereby task-switching would otherwise typically afford inner speech in addition to visuospatial resources.

However, the results thus far may reflect deficits in the use of inner speech for arithmetic problems generally, or at most arithmetic task-switching specifically. Intact mediation by the visuospatial component of working memory in autism may also be limited to these task contexts. Further examination of the recruitment of inner speech and visuospatial resources for managing an alternative central executive task may clarify the extent to which these components generally service the control of thought and action in autism.

EXPERIMENT 3

The ToH is an executive task that is related to visuospatial planning ability and goal management, and is widely used in studies of autism whereby significant group differences in task performance are routinely reported (e.g. Hill, 2004; Hughes, Russell, & Robbins, 1994; Pennington & Ozonoff, 1996). Compared with the arithmetic list paradigm, the ToH is also clearly based on a visuospatial display. As such, the use of the ToH in Expt 3 enabled an examination of: (1) whether the difficulties experienced by CWA in recruiting inner speech for controlling action are limited to the context of arithmetic task-switching or generalized to other central executive skills such as visuospatial planning and (2) whether visuospatial resources remain available to CWA for servicing executive capacity. In Expt 3, participants were required to complete a modified version of the ToH task under the three suppression conditions as outlined in Expt 2: silence, AS, and VSS.

While the display and response requirement of the ToH are visual and spatial, there is research indicating that the regulation and direction of action plans can be carried out by verbal representations (e.g. Fernyhough & Fradley, 2005; Morris, Ahmed, Syed, & Toone, 1993) or visuospatial resources in working memory (e.g. Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999). Across Expts 1 and 2, the TD groups’ task-switching completion time was similarly affected by AS and VSS output conditions. We predicted that ToH task performance by TD participants would also be similarly affected by AS and VSS output conditions compared to a silent condition. For the CWA group, because individuals with the disorder do not adopt inner speech to service executive control, we predicted a ToH performance cost in the VSS condition but not in the AS condition. Based on the findings of Expt 2, we also predicted that the impact of VSS on task performance would be equivalent upon the two groups.

Method

Participants

The participants were the same as those in Expt 1. Each participating family was contacted 2 weeks after the completion of Expt 2 and all families gave informed consent for their child to participate in Expt 3.

Materials

All participants were invited to complete the ToH under three conditions (silent, AS, and VSS). The ToH task consisted of a wooden base with three wooden pegs upon which
pre-arranged disks needed to be moved to form a particular arrangement. As in the previous experiments, a white plastic board with nine blue blocks attached was used for the VSS condition. A metronome was used to control the rate of AS and VSS, and was set to the same rhythm used in Expts 1 and 2 (60 beat/min). The experimenter used a stopwatch to time the completion of the ToH tasks in seconds.

Procedure
Participant testing was carried out in the same manner as described for Expt 1. A within-subjects design was followed whereby all participants completed one ToH trial for each condition (silent, AS, and VSS). The ToH required participants to plan a sequence of moves to achieve a desired goal pattern. This pattern was presented to participants as a picture of the final result, to which they were able to refer throughout the task. The rules were that only one disk could be moved at a time and that a larger disk may not be placed on a smaller one. The full ToH task comes with nine trials of increasing difficulty that are presented sequentially to test overall planning ability (Delis, Kaplan, & Kramer, 2001). However, the latter trials require a more complex set of submovement plans, several of which are counter-intuitive in relation to the final goal state. For successful task completion on the latter trials, these micro-moves need to be considered in terms of how they relate to the entire planning procedure to eventually enable a critical move to be made. The latter trials not only require a higher level of visuospatial planning, but also involve significant demands associated with the processing of several spatial moves that are hierarchically organized and relationally complex (Halford, Wilson, & Phillips, 1998). CWA have been found to exhibit difficulties not only with planning (e.g. Prior & Hoffmann, 1990), but also with the hierarchical embedding of relational rules (e.g. Zelazo, Jacques, Burack, & Frye, 2002). The overall performance of CWA on a ToH task that included all nine trials may mask or dilute any effects of the experimental suppression conditions employed here. To control for significant relational complexities that are especially apparent in the last four trials of the ToH task, we decided to use only the fifth ToH trial for all three output conditions in this experiment. This fifth ToH trial required a minimum of seven moves for successful completion. Another advantage to this decision was that participants were able to practice following the ToH rules on the first four trials prior to the presentation of the fifth test trial.

There were three output conditions: silent, AS, and VSS. The baseline silent condition required participants to silently complete the ToH test trial as fast and as accurately as possible. The AS condition was conducted as described in Expt 1, except that the vocalization of the days of the week was changed from reciting days of the week to reciting months of the year, to prevent participants habituating to the words recited in conjunction with the arithmetic tasks. As in Expt 1, participants were required to articulate the months of the year, in order and beginning with ‘January’, in time with the metronome. The VSS condition was carried out as described in Expt 2. Participants were given as much articulation and visuospatial sequential tapping practice as required to ensure that all suppression was produced in time with the metronome. In order to minimize practice effects stemming from a within-subjects design involving a single ToH trial, the presentation of the output conditions was counterbalanced across participants using a Latin square. During the suppression testing conditions, all participants were able to verbalize or tap to the beat of the metronome and no one appeared to stray from
the rhythm. We also imposed a 5-min gap between conditions whereby the experimenter engaged the participant in filler tasks involving non-ToH related activity (e.g. playing with toys) to further minimize practice effects.

**Results**

The time taken to complete the ToH and the number of moves made were the dependent variables. Preliminary analyses indicated that order of presentation of condition for the ToH task was not a significant main effect and did not interact with any of the other variables, and hence condition order was not included in the analyses reported here. ToH completion time data for the three conditions for both groups are presented in Figure 3. The data was analysed through a 2 (group: CWA vs. TD) × 3 (condition: silent, AS, vs. VSS) ANOVA with condition as a within-subjects factor.

There were significant main effects of group \( (F(1, 24) = 4.72, \ p < .05, \ \eta^2_p = .16) \) and condition \( (F(2, 23) = 31.33, \ p < .001, \ \eta^2_p = .73) \). However, these main effects were qualified further by a significant group × condition interaction \( (F(2, 23) = 9.70, \ p < .01, \ \eta^2_p = .46) \). This interaction was interpreted in terms of how completion time was affected as a function of condition for each group. It was also broken down in terms of how completion time in each individual condition varied according to group.

Simple main effects analysis indicated a significant effect of condition for CWA \( (F(2, 11) = 9.94, \ p < .01, \ \eta^2_p = .64) \). For the CWA group, pairwise comparisons with Bonferroni adjustments indicated that ToH completion time in the VSS condition \( (M = 32.79; \ SD = 15.89) \) was significantly slower compared to performance in the

![Figure 3. Mean completion time for ToH planning task under various suppression conditions by group (error bars represent 1 SE of the mean).](image-url)
silent \((M = 14.79; SD = 5.08)\) and AS conditions \((M = 14.10; SD = 4.53; all \ p < .01)\). For CWA, there was no significant difference in completion time between the AS and silent output conditions \((p > .05)\). Simple main effects analysis also indicated a significant effect of condition for the TD group \((F(2, 11) = 21.45, p < .001, \eta_{p}^{2} = .80)\). For the TD group, pairwise comparisons with Bonferroni adjustments indicated that ToH completion times under the VSS condition \((M = 36.50; SD = 12.48)\) and the AS condition \((M = 29.07; SD = 10.93)\) were slower than completion time in the silent condition \((M = 12.48; SD = 3.89; all \ p < .01)\). For the TD group, there was no significant difference in ToH completion time between the VSS and AS conditions \((p > .05)\).

In the silent condition, there were no significant differences in ToH completion time between the CWA and the TD groups \((t(24) = 1.30, p > .05)\). For the VSS condition, there was no significant difference in ToH completion time between the two participant groups \((t(24) = .66, p > .05)\). However, for the AS output condition, the TD group took longer to complete the ToH compared to the CWA group \((t(24) = 4.56, p < .001)\).

A separate 2 (group) × 4 (condition) ANOVA was also conducted on the total number of moves taken to complete the ToH task under the respective suppression output conditions. There were no statistically significant effects.

**Discussion**

Expt 3 indicated that for the TD group, the imposition of AS and VSS similarly affected the latency of ToH planning. Complementing the findings of Expts 1 and 2, the results of Expt 3 suggest that, in normal development, children are able to spontaneously use verbal and visuospatial representations to augment central executive skills in monitoring and maintaining a sequence of plans. Of course, these results should not be taken to imply that TD children do not flexibly switch strategies or differentially allocate strategy representations to suit task circumstances (e.g. Hitch, Woodin, & Baker, 1989; McKenzie *et al.*, 2003). Our findings that the TD group was similarly affected by AS and VSS only suggest that in normal development a mixture of verbal and visuospatial strategies are available for representational elaboration. The results of Expt 3 were further consistent with those of Expt 2 in that there was no differential dependency upon the visuospatial sketchpad of working memory by the CWA group compared to the TD group in the VSS condition. The VSS condition results indicated that both CWA and TD groups were similarly capable of exploiting visuospatial representations to enhance the regulation of planning by the central executive. CWA appeared to be different from participants in the TD group in that participants with the disorder mainly seemed not to additionally rely on language-based representations to enhance central executive task performance.

**GENERAL DISCUSSION**

Whitehouse *et al.* (2006) were the first to show that CWA are impaired in their use of inner speech for task-switching as reflected in a dual-task methodology involving the arithmetic list paradigm. The present investigation replicates and extends their work in important ways. In Expt 1, unlike the TD participants, CWA exhibited no detriment to arithmetic task-switching performance despite the suppression of inner speech. The
divergence in performance between groups also fits with the fact that language ability was negatively correlated with an AS cost to the alternating arithmetic task for the TD group but not the CWA group. CWA do not appear to use their verbal skills to enhance task-switching performance. Indeed, CWA, unlike the TD group, even showed no detriment to performance on the ToH planning task despite the suppression of inner speech. In autism, there appears to be a failure to use inner speech to facilitate executive performance in multiple cognitive domains (e.g. Joseph et al., 2005; Russell et al., 1999). This study also supports Whitehouse et al.'s (2006) suggestion that whilst CWA may not use inner speech for arithmetic task-switching, they may be able to exploit visuospatial representations to enhance central executive performance in maintaining changing response rules to generate appropriate responses. Given the preference towards visuospatial representations early in development (Williams et al., 2008), and how separate but complementary verbal and visuospatial resources in working memory are available for problem solving (e.g. Kübler et al., 2003; McKenzie et al., 2003), one likely source of contribution to supporting central executive performance is the visuospatial sketchpad component of working memory. In Expt 2, both participant groups demonstrated a detriment to arithmetic task-switching completion time (and general blocked arithmetic task completion time) with the suppression of visuospatial working memory resources. The impact of VSS on blocked and task-switching trials dovetails with broader literature suggesting close connections between visuospatial sketchpad of working memory and mental arithmetic performance and how basic arithmetic computations may be represented in terms of analogue magnitude by way of a number line (e.g. Dehaene, 1997; Lee & Kang, 2002). However, Expt 3 also indicated that visuospatial mediation in autism was not confined to the context of arithmetic problem solving, but was extended to other domains such as planning. These results, overall, reveal that the ability to recruit visuospatial representations from the sketchpad working memory component for servicing central executive performance remains intact in CWA.

A further aspect of the findings across the three experiments was that for both conventional central executive tasks, task-switching, and ToH planning, the two groups of participants showed equivalent performance under the VSS output condition, despite a lack of inner speech contribution to task performance in the CWA group. In some ways, this result prevents a precise consideration of strategy differences between the CWA and TD groups. Nonetheless, our findings are important in the sense that whilst CWA are limited in their exploitation of inner speech to support the operations of the central executive, they do not appear to over-rely on visuospatial representations for problem solving. The results fit with a broad range of literature indicating that: (1) CWA show an uneven profile of intact as well as impaired visuospatial memory capabilities (e.g. Caron et al., 2004; Edgin & Pennington, 2005; Minshew & Goldstein, 2001); (2) visual thinking is not the only problem-solving strategy available to CWA (e.g. Williams et al., 2008); and (3) CWA show impoverished elaboration in problem-solving contexts that typically afford multi-representational enhancements (e.g. Joseph et al., 2005; Whitehouse et al., 2006). Overall, it appears that amongst CWA, visuospatial but not inner speech resources contribute to supporting the switching of attention and planning by the central executive when external cues that signal what operation or move to perform next are limited, and some form of endogenous mediation is needed.

Our findings are, however, constrained by the relatively small-sample size tested and the results will need to be replicated. In this group of CWA, there were no control
condition differences in task performance in comparison to the TD group. It would be important to learn what pattern of results would occur in CWA who do not perform executive tasks as well as TD children. Future research could manipulate the complexity of the primary task (e.g. using the full ToH battery, using multi-digit arithmetic tasks with varying presentations) to determine the precise involvement of verbal and visuospatial representations from the working memory slave systems that are recruited to service the central executive in CWA. For example, in normal development, mental additions that are presented vertically require more visual resources compared to horizontal format problems (e.g. Trbovich & LeFevre, 2003); it would be important to determine whether performance by CWA is also worse when solutions to vertical compared to horizontal arithmetic problems are output under VSS. Such findings will be important for understanding whether CWA can strategically recruit visuospatial representations to better support particular types of problem solving. Finally, throughout the three experiments, the use of the metronome was effective to the extent that the consistent beat ensured that all participants did not stray in the rhythm of their articulation and sequential tapping during the secondary task. Given that we did not formally audio-record secondary verbalization or video-record secondary sequential tapping, we were not able to systematically evaluate any subtle latency or period changes as a result of dual-task demands. Future research could also examine whether there might be any potential tradeoffs between performance of CWA on the primary and secondary tasks in dual-task situations.

If CWA do attempt to solve tasks through visuospatial mediation, why do such individuals still experience significant difficulties with a range of executive function tasks that include planning and mental switching (e.g. Hill, 2004; Zelazo et al., 2002)? There are several possibilities. First, we need to remember that the central executive in working memory, aside from receiving input from the phonological loop and visuospatial sketchpad subsidiary systems, has its own specific subprocesses for controlling, inhibiting, selecting, dividing, and switching attention (Baddeley, 1996). Consequently, even though problem-solving approaches in CWA may be mediated by the visuospatial sketchpad component, these individuals may experience particular deficits in the controlling functions that are unique to the central executive itself. One way to further study the mechanisms underpinning difficulties with planning, inhibition, and task-switching may be, for example, to assess whether and how secondary tasks requiring overt articulatory rehearsal (tapping the phonological loop), sequential tapping (tapping into the sketchpad), and verbal trail making (e.g. interleaving days of the week with months of the year; tapping into the central executive) differentially affect performance of CWA on particular tasks of executive function (cf. Baddeley et al., 2001). One of the core problems faced by CWA when strategically approaching non-routine tasks, besides the diminished quality of service provided by inner speech, may relate to particular operations performed by the central executive itself. Second, visuospatial mediation that is worked out in the sketchpad may not necessarily activate abstract meta-intentional understandings that may be crucial to the ensuring the effective coordination of duties performed by the central executive. CWA may fall short in their overall central executive capabilities because of their inability to represent their own act of wanting or entertaining certain goals (Perner, 1998). Finally, visuospatial strategies, whilst providing an important resource for executive problem solving in CWA, may not be as useful as covert self-cueing via inner speech. Emerson and Miyake (2003) make an important point that speech (overt or covert) is highly sequential in nature and, as such, can help children keep track of which
task, move, or operation they need to perform next. They also point out that the brevity of how much we can internally subvocalize could be a boon in that it helps us focus on the most relevant aspect of the task at hand. Furthermore, the recruitment of verbal representations for the service of the central executive may also permit more significant cognitive flexibility in the sense that it can trigger, encapsulate, or activate other kinds of understanding (e.g. semantic networks, mental state representations, task goals, and meta-intentions) that allows fairly complex reasoning and problem solving (e.g. Carruthers, 2002). It may be that irrespective of visuospatial resources being available and spontaneously recruited to service the central executive, fluctuations in the quality of how inner speech services the control of thought and action could lead to an uneven profile of executive dysfunction in CWA.

Inner speech may be available to CWA for short-term maintenance and storage of verbal and phonological information, but even then there may be irregularities - reduced word-length and picture superiority effects (Whitehouse et al., 2006) but clear phonological similarity effect (Williams et al., 2008). However, autistic weaknesses in inner speech use may be much more evident in terms of when and how subvocal rehearsal is recruited to support central executive control processes. To that extent, there may be a larger and more robust effect whereby AS does not affect task-switching and planning performance in CWA, as was found in the present investigation. For CWA, there may be more variability, or perhaps noise, in how covert articulatory rehearsal via inner speech is implicated beyond the phonological loop component of working memory. This rapprochement fits with Williams et al. elegant suggestion that the diminished recruitment of inner speech for servicing the central executive may reflect CWA being less likely to use inner speech in a fully dialogic manner (i.e. to oneself as opposed to for oneself). Nonetheless, we do not wish to foreclose on the possibility that CWA may be able to use inner speech to support executive control process in more circumscribed ways. We are mindful that our results may be limited to CWA not using inner speech for arithmetic task-switching and ToH planning specifically. Further research will be necessary to test whether CWA show detrimental effects of AS when performing other tasks associated with central executive functioning (e.g. the Wisconsin Card Sort Task, the Dimensional Change Card Sort task; e.g. Ozonoff, 1995; Zelazo et al., 2002). Central executive skills such as inhibitory control have also been found to be associated with theory of mind reasoning such as false-belief understanding, for TD and CWA groups (e.g. Hughes, 1998; Russell, Saltmarsh, & Hill, 1999). Correspondingly, another approach to extending the theoretical reach of our current data would be to test whether AS affects accuracy and latency of false-belief reasoning in CWA. Research testing the generalisability of AS effects in autism will be worthwhile.

In conclusion, there seems to be a strong effect whereby CWA do not appear to be disrupted by AS when performing task-switching operations and when executing planning movements. In contrast, CWA appear to be affected when these tasks are output under VSS conditions. When framed against extant research, the general findings suggest that whilst the mechanism for engaging in inner speech for short-term recall may be unimpaired in CWA, participants with this disorder seem to fail to recruit inner speech for central executive assistance. CWA remain, however, capable of recruiting visuospatial resources for mental switching and planning. It remains for future research to discover whether visuospatial mediation compared to problem-solving elaboration that utilizes a mixture of verbal and non-verbal representations affords CWA the same quality of central executive support.
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