Working memory in children and adolescents with Down syndrome: evidence from a colour memory experiment

Glynis Laws

University of Oxford

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Correspondence to:

Glynis Laws

Department of Experimental Psychology,

University of Oxford,

South Parks Road,

Oxford OX1 3DU

Tel: +44 (0)1865 271334

Fax: +44 (0)1865 281255

E-mail: glynis.laws@psy.ox.ac.uk

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This paper reports information on the visual and verbal short term memory of individuals with Down syndrome. Colour memory in 16 children and adolescents with Down syndrome was compared with that of 16 typically developing children matched for receptive vocabulary. It was suggested that focal colours should be remembered more successfully than non-focal colours on the basis that the former could be remembered using a verbal recoding strategy. However, children with Down syndrome, for whom a deficit in verbal short term memory makes the use of such a strategy unlikely, should remember focal and non-focal colours equally well. More importantly, if individuals with Down syndrome have more developed visual memory abilities than control children, they should out-perform them in recognising non-focal colours. Although the group with Down syndrome demonstrated significantly better Corsi blocks performance than controls, and displayed similar levels of colour knowledge, no advantage for colour memory was found. Non-focal colours were remembered by individuals with Down syndrome as successfully as focal colours but there was no indication of a visual memory advantage over controls. Focal colours were remembered significantly more successfully than non-focal colours by the typically developing children. Their focal colour memory was significantly related to digit span, but only Corsi span was related to focal colour memory in the group with Down syndrome.

(217 words)

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Introduction

Somewhere around 1 in 1000 babies are born with Down syndrome (Steele, 1996). Improved health care and education, and the resulting increases in survival and life expectancy, make this probably the largest population with a learning disability of known biological cause. In most cases (95%-98%), Down syndrome is caused by trisomy 21 but research indicates wide variation in the effects of the chromosomal abnormality on development and paints a picture, not of global retardation, but of a profile of relative strengths and weaknesses across domains.

The short term memory development of individuals with Down syndrome has been the subject of considerable research. Much of this work has been conducted within the framework of the working memory model (Baddeley, 1986; Baddeley & Hitch, 1974), which specifies a separation of functions for the processing of verbal material (the phonological loop) and visuo-spatial material (the visuo-spatial sketch pad). The phonological loop is conceptualised as a limited capacity store to which spoken words gain direct access, and an articulatory rehearsal mechanism that allows words to be maintained in the store by a process of subvocal rehearsal. Recent research suggests a similar separation of storage and maintenance functions in the visuo-spatial sketch pad (Logie, 1995, 1996). However, the articulatory rehearsal mechanism serves the additional function of translating written words or pictures to a verbal code and thus offers an alternative strategy for remembering visual material, referred to as phonological or verbal recoding.

Children are thought to begin to use subvocal rehearsal at around 7 years of age (Cowan & Kail, 1996; Baddeley, Gathercole & Papagno, 1998; Gathercole & Hitch, 1993). Much of the available evidence suggests that verbal recoding of picture material is also reliably established at about the same age and that, before this strategy is adopted, children prefer visual encoding (e.g. Brown, 1977; Hayes & Schulze, 1977; Hitch, Halliday, Dodd & Littler, 1989; Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Woodin & Baker, 1989). Recent observation of the development of encoding strategies through the ages of 5 to 8 years suggests that this is a complex process involving the maturation of attentional and inhibitory processes (Palmer, 2000). Children progress from using no obvious strategy for remembering pictures to using visual encoding, then to the use of both visual and verbal codes, and finally to a mature state where more efficient verbal encoding is preferred. Palmer (2000) suggests that both visual and verbal codes are available from an early age, that both remain available as strategies in the mature state, and that what develops with the shift from a preference for visual to verbal encoding are those processes necessary for the inhibition of the visual code.

Palmer's research showed a group effect for verbal recoding of pictures emerging in six year olds, but there were individual differences between the children in all the age-groups studied, with a few 5 year olds using verbal recoding, and a few 8 year olds hanging on to a visual strategy. These findings were based on the observation of experimental effects as well as the self reports of children when asked about how they had tried to remember the stimulus pictures. They are supported by other research reporting verbal encoding of pictures by young children from four years of age (Alegria & Pignot, 1979; Henry, Turner, Smith & Leather, 2000; Hitch et al, 1988; Hulme, 1987; Hulme, Silvester, Smith & Muir, 1986).

Memory investigations of individuals with Down syndrome support the notion of a selective impairment of the phonological loop component of working memory (e.g. Jarrold & Baddeley, 1997). Given the probable importance of the phonological loop for learning language (Baddeley, et al, 1998; Gathercole & Baddeley, 1993), this impairment could have important consequences for language development in Down syndrome (Chapman, 1995; Fowler, 1995; Laws, 1998; Laws & Gunn, in preparation). For this reason, in part, it has been the main focus of interest for memory research and there has been less interest in understanding more about the relative strength in visuo-spatial memory abilities implied by the research.

While understanding the nature of deficits is important, it is as important to be clear about the nature and extent of developmental strengths if these are to be capitalised on effectively in intervention. Remediation may work best when it targets resources rather than deficits (Gibson, 1996), and avoids the frustration that may follow attempts to work on problem areas such as the auditory system (Pueschel, 1988). Practitioners recognise a visual processing advantage in individuals with Down syndrome, and parents and teachers are encouraged to provide visual learning materials and experiences (e.g. Buckley & Bird, 1993; Freeman & Hodapp, 2000). However, it is not clear if any visual processing strength is due to encoding differences, where a relatively permanent visual stimulus offers an advantage over a relatively transient auditory stimulus, or whether individuals with Down syndrome are also able to maintain some kind of mental picture of a stimulus prior to recall or recognition. If this were so, it could extend the scope of interventions to those that depend on developing this capacity specifically. For example, teaching a visualisation strategy could be useful for improving reading comprehension which can be problematic even for individuals with Down syndrome with good word decoding skills (see Farrell, 1996).

The majority of research on short term memory in Down syndrome has measured digit span to assess the verbal component of working memory. Digit span is typically poorer than performance on the visual memory subtest of the Illinois Test of Psycholinguistic Abilities (Bilovsky & Share, 1965; Marcell & Armstrong, 1982), or the bead memory test of the Stanford-Binet Intelligence Scale (Thorndike, Hagen & Sattler, 1986) (Kay-Raining Bird & Chapman, 1994). Several studies contrast digit span with Corsi span, argued to be a better test of visuo-spatial memory since it is not open to the use of verbal strategies in its completion (Azari, et al., 1994; Fowler, Doherty & Boynton, 1995; Jarrold & Baddeley, 1997; Vicari, Carlesimo & Caltagirone, 1995; Wang & Bellugi, 1994). These studies indicate an advantage for Corsi span over digit span for individuals with Down syndrome, which is the reverse of the pattern expected for the general population. For example, a group of young adults with Down syndrome studied by Fowler, Doherty and Boynton (1995) had a mean digit span equivalent to that expected in typically developing children of 5 years, but an estimated age equivalent mean score for the Corsi blocks test of 6.4 years. Jarrold and Baddeley (1997) found the same pattern of results for a group of children and adolescents with Down syndrome, but vocabulary matched children with other learning disabilities and younger typically developing children had higher digit spans than Corsi spans. Although these studies provide evidence for a dissociation between verbal and visuo-spatial short term memory abilities, it is not clear from them how stimulus information in the Corsi task, which includes visual and spatial components, is maintained.

One indication that this relative strength could be related to visual memory abilities is provided by the contrast between auditory digit span and memory for printed digits. Broadley, MacDonald and Buckley (1995) reported that printed digits resulted in significantly better performance than that achieved with auditory stimuli alone. Other research has failed to find such a strong advantage for printed digits (Marcell & Armstrong, 1982), but more reliable modality effects have been suggested in research on memory training where studies report a significant advantage for picture memory over serial recall of words after the training (Broadley & MacDonald, 1993; Comblain, 1994; Laws, MacDonald & Buckley, 1996).

The rationale for memory training is based on developing an active verbal rehearsal strategy. Rehearsal strategies do not seem to emerge spontaneously in individuals with Down syndrome, leading to suggestions that the memory deficit could be due to a problem with the articulatory rehearsal component of the phonological loop (Hulme & Mackenzie, 1992). Although recent evidence suggests that the deficit may reflect limitations in the phonological store rather than of the articulatory rehearsal loop (Jarrold, Baddeley & Hewes, 2000), teaching a cumulative rehearsal routine using sequences of pictures has resulted, nevertheless, in significantly improved memory spans for pictures. Although some increase in memory span for spoken words occurs after rehearsal training, this is very much smaller than the gains for pictures (Broadley & MacDonald, 1993; Laws et al, 1996). For example, Broadley and McDonald (1993) reported an increase in span of 2.25 words for verbal recall of pictures of one-syllable words but, with auditory presentation, the increase in span was limited to 0.52.

Interpretation of such results is not straightforward. The modality difference could be simply due to poor generalisation from the picture-based training to a task requiring serial recall of auditory stimuli. Alternatively, individuals may learn to rehearse after verbal recoding of picture stimuli, but encoding spoken words may continue to be difficult for them so that they fail to make similar progress on serial word recall. In relation to the working memory model, this could be explained as a continuing problem with the direct route for spoken words to the phonological store while the indirect route, which involves verbal recoding by the articulatory rehearsal mechanism, is intact. Another explanation is that the training practice actually improves visual memory for pictures as well as, or instead of, teaching individuals to rehearse the names of the pictures. In the light of the more theoretically informed research contrasting digit span and visuo-spatial memory abilities described earlier (e.g. Jarrold & Baddeley, 1997), it seems plausible that a visual memory strength could play some part in the picture memory success reported in training studies.

One aim of the present experiment was to establish whether individuals with Down syndrome demonstrate an advantage for visual memory independent of that which could be attributed to initial encoding of stimuli. The comparison of digit span and Corsi span tasks described in earlier studies was replicated, but this study also investigated the colour memory skills of children and adolescents with Down syndrome and compared them with a group of typically developing children matched for receptive vocabulary. By comparing memory under two conditions which both involved presentation of visual stimulus material, differences in performance across conditions should be attributable to processing differences taking place after initial registration of the stimuli. This should make it possible to rule out difficulties with hearing or initial encoding of stimuli as explanations for performance deficits in those with Down syndrome. The experimental tasks selected, and described below, controlled the strategies available to participants by comparing visual memory for stimuli where verbal recoding would be possible with those where it would be difficult to employ this strategy. This allowed the visual memory abilities of the two groups to be compared, and also provided the basis for an investigation of verbal recoding of visual material in both groups.

The rationale for the colour memory experiment was derived from research where colour memory has been studied to test Whorfian hypotheses of linguistic relativity (see Bornstein, 1975; Davidoff, 1991; Miller & Johnson-Laird, 1976, pp. 333-360). In this tradition, the fact that languages differ in the ways in which the colour space is encoded has been exploited to investigate the influence of linguistic differences on colour perception, colour categorisation or colour memory (e.g. Davies & Corbett, 1997; Heider & Olivier, 1972; Kay & Kempton, 1984; Laws, Davies & Andrews, 1995). For English speakers, the colour space is divided into eleven basic colour categories (Berlin & Kay, 1969). The best examples of each category constitute a prototype and form the focus of the category. With increasing distance from these focal colours, and especially towards category boundaries, colours become less easy to name. Reaction times to name focal colours are faster than for non-focal colours, and there is greater consistency within individuals and consensus among individuals in their naming (Boynton & Olson, 1987, 1990). Non-focal colours take significantly longer to name, and may attract a variety of basic and non-basic terms. For example, a colour near the category boundary between green and yellow might correctly be called 'green', 'yellow', 'lime', 'chartreuse' or by some other idiosyncratic name.

These features of colours and colour names, particularly the added difficulty in naming non-focal colours, have an impact on colour memory performance. Memory for individual colours is related to how easily they can be verbally communicated (Brown & Lenneberg, 1954; Lantz & Stefflre, 1964). Remembering focal colours is therefore generally more successful than remembering non-focal colours because a verbal coding strategy can be used for the task (Davidoff & Ostergaard, 1984; Garro, 1986; Lucy & Shweder, 1979; Ridley, 1985). Although others (e.g.

Heider, 1972) have argued that perceptual salience rather than codeability may determine how well colours are remembered, this has been on the basis of evidence from experiments offering a large number of target stimuli where focal and non-focal colours have been intermixed. Under these conditions, perceptual discriminability may be as important a determinant of successful recognition as codeability (Garro, 1986). With a small number of perceptually distinct targets, and a procedure which offers focal and non-focal colours in separate conditions, this would not be an issue.

Participants completed a colour memory task under two conditions; one which offered focal colour stimuli, i.e. typical examples of the English basic colour categories, and one which offered non-focal colour stimuli, i.e. those from category boundary regions with indeterminate names. If children use a verbal recoding strategy, focal colours should be recalled more successfully than non-focal colours which are not easily named. The individuals with Down syndrome were predicted to remember colours equally well in both conditions since the phonological deficit associated with the syndrome made it unlikely that verbal recoding and rehearsal of colour names would be used as a strategy for remembering focal colours. Further, in relation to the question of whether individuals with Down syndrome have a particular strength in visual memory, this would be demonstrated in superior memory for non-focal colours compared to controls, since memory for these colours should depend on successful maintenance of a visual representation of the colour stimuli. The control children were predicted to remember focal colours more successfully than non-focal colours on the basis that a verbal recoding strategy could be used for the former class of colours. However, this was a more tentative prediction since, as discussed, there are inconsistencies in the findings of earlier research to establish the age at which verbal recoding is reliable.

Long term knowledge may also contribute to short term memory performance, and several studies have shown that children’s short term memory is better for familiar than unfamiliar items (e.g. Gathercole & Adams, 1994; Henry & Millar, 1991; Hulme, Maughan & Brown, 1991; Roodenrys, Hulme & Brown, 1993). This can be explained by versions of the working memory model which suggest that auditory, visual or semantic representations of stimuli must first be activated in long term memory before they become available for processing by the phonological loop or other components of the model (see Palmer, 2000 for discussion). It was therefore important to assess colour knowledge in the two groups to ensure that any differences in performance could not be attributed to a lack of long term representations of colour names by the children with Down syndrome. To assess colour knowledge, three tasks were administered involving colour listing, colour identification and colour comprehension.

Method

Participants

Sixteen children and adolescents with Down syndrome took part: 8 boys and 8 girls aged from 7 years 5 months to 17 years 10 months (mean=11;08, SD=3;05). All attended schools for children with severe learning difficulties, except for four children who were enrolled at mainstream schools. The children were matched individually on the basis of receptive vocabulary to a control group of typically developing children which included 10 boys and 6 girls. The control children were aged from 2 years 9 months to 6 years 11 months (mean=4;06, SD=1.01) and attended a number of different nursery or primary schools. No assessment of the children's colour vision was made but the levels of performance on the colour identification and comprehension tasks described below gave no cause for concern.

Measures

In addition to the colour memory tests offered, measures were selected to give a picture of each child's verbal and nonverbal cognitive ability, their verbal and visuo-spatial memory, and knowledge of colours and colour terms.

British Picture Vocabulary Scale II (Dunn, Dunn, Whetton & Burley, 1997). This is a measure of receptive vocabulary which requires the selection of the correct picture from a set of four to match a word spoken by the examiner. The procedure and scoring instructions provided in the manual were followed and raw scores used to identify children for the control group.

Ravens Coloured Progressive Matrices (Raven, 1963). This test was used to assess nonverbal cognitive ability.

Digit span. Auditory digit span was assessed using the number sequences and procedure described in the McCarthy Scales of Children's Ability (McCarthy, 1972). In this procedure, two test items are presented at each sequence length. The number of correct items was recorded as a digits score, and a digit span was calculated as the longest sequence of digits recalled correctly.

Corsi blocks test. The apparatus for this task consisted of a wooden board on which were mounted nine small blocks arranged in a random fashion (Milner, 1971). The experimenter pointed to a sequence of blocks at a rate of one per second and the child was asked to imitate the sequence. The sides of the blocks facing the experimenter were numbered to facilitate administration of the test, and the sequences presented were the same as those used for digit span. Trials and scoring were carried out in the same way as for digit span.

Verbal fluency (McCarthy, 1972). Each child was asked to list examples from four categories: clothing, things to eat, things to ride on and animals. To allow for the slower processing time of children with Down syndrome, 60 seconds were given for each category rather than the usual 30 seconds. All valid examples were scored.

Colour knowledge tasks

I *Colour listing*, "Tell me the names of all the colours you know".

As for the verbal fluency test, one minute was allowed for listing colours. The number of colour names listed was recorded.

II *Colour identification*, "What is the name of this colour?"

Stimuli for this and the other colour tasks consisted of two sets of tiles featuring 11 focal and 8 non-focal colours respectively (see Appendix). The set of nonfocal colours was limited to 8 to match the set size of the 8 chromatic focal colours that were to be used as stimuli in the memory experiment (see below). Each tile measured 6 cm by 6 cm. Each set in turn was presented, one tile at a time, in random order, and the child was asked to name each one. In this and the other colour tasks, tiles were shown against a neutral grey background cloth. Responses to each tile, and whether they were correct or incorrect were recorded. Responses to non-focal colours were recorded as correct when they were either a basic name for one of the categories in which the colour was a member or an appropriate specific name (e.g. a blue-green tile could reasonably be labelled 'blue' or 'green' or 'turquoise', 'aqua' etc.). The number of correct responses to each set was calculated.

III *Colour comprehension* "Can you point to the 'green' tile?"

Only the focal colour set was used in this task since the lack of consensus on the names of the non-focal colours would have made it too complicated to use them in this task. The tiles were arranged on the background cloth and the experimenter asked the child to point to each tile in turn in response to a basic colour name. Responses were recorded as correct or incorrect.

<u>Colour memory task</u>

The task required the child to remember sequences of coloured tiles under two conditions; in one the stimuli were drawn from the set of eight chromatic focal colours and in the other the stimuli were from the same size set of non-focal colours. In both conditions, responses involved the identification of the stimulus tiles from a response array consisting of all eight colours in the set.

Before testing, each child was first trained with no memory requirement to ensure that the notion of matching stimuli was understood. The set of eight chromatic focal colour tiles was displayed in a row on the neutral grey cloth; this was the response array. A stimulus tile from a corresponding identical set was then placed above the array and the child was asked to look at it carefully. The experimenter asked the child to point to the tile in the response array which matched the stimulus tile. When it was clear that the matching procedure was understood with stimulus tile and response array both visible, training on the memory task was given. This followed the same procedure except that the response array was covered while the stimulus tile was presented. After an exposure of 5 seconds, the stimulus tile was covered and the response array was then revealed. The child was asked to indicate the tile in the response array which matched the one he or she had been shown.

Trials began with one target tile and proceeded to two tiles, then three tiles and so on. Only one tile of each colour was ever included in a trial. Two trials were provided at each sequence length. To succeed on a trial, all presented tiles had to be correctly identified from the response array. In order to minimise task response demands, it was decided not to insist on correct order as well as identification. Correct order information would have required participants to scan the array, select the correct tiles and then re-order them for their response. The additional processing time could have reduced the performance of the group with Down syndrome differentially by extending the time required to formulate a response, and thus the period over which a representation in memory would need to be maintained.

Testing ceased when both trials were failed at a given sequence length. Stimulus colours were selected from the set at random with the exception that, for the first trial, a different tile was presented from the one that had just been used in training. On completion of the task using one colour set, the task was repeated with the other set following the same procedure. For each condition, a colour memory span was calculated as the longest sequence successfully recalled, and a colour memory score was calculated as the number of test items correctly recalled.

Procedure

All the children were visited and tested individually in school or nursery; one or two sessions were required to complete the testing, depending on each child's concentration and motivation. Presentation of the two colour memory tasks was counter-balanced; half the children in each group were given focal colour stimuli first and the other half were given non-focal colour stimuli. The colour knowledge tasks were administered last with colour listing, colour identification and colour comprehension presented in that order so that the names provided by the experimenter in the comprehension task could not be used as cues in the other tasks.

Results

Table 1 describes the chronological ages, vocabulary, verbal fluency, non-verbal cognitive ability, digits scores and Corsi scores (i.e. total number of correct items) for the two groups of children. Age equivalent scores are given for vocabulary and nonverbal tests; it was not possible to derive standardized scores for these measures for the participants with Down syndrome since many of them are beyond the age range covered by the norms tables. Independent t-tests confirmed that there were no significant differences between the groups for receptive vocabulary or verbal fluency; the differences in means between the groups' Ravens scores approached significance ($t(24) = -1.98$; $p = 0.08$).

Table 1 about here

Digit span and Corsi span tasks

Table 1 shows a clear difference between the groups in the pattern of scores achieved on digit span and Corsi tests. A two factor analysis of variance (ANOVA) investigated the between group effect with task included as a repeated measures factor. There was no significant group effect (means across digit scores and Corsi scores: Down syndrome = 2.91; Controls = 3.47), and no overall effect of task (mean digits score = 3.19; mean Corsi score = 3.19), but there was a highly significant interaction between group and task ($F(1,30)=46.47$; $p<0.0001$). Investigation of the interaction showed that whereas mean digit score was significantly higher for the typically developing group than for the group with Down syndrome ($t(24.94)=-4.20$, $p<0.0001$), Corsi scores were significantly greater for the group with Down syndrome than controls ($t(30)=4.05$, $p<0.0001$). These results support the claim for a phonological deficit in Down syndrome combined with a relative strength in visuo-spatial memory.

Colour memory

The mean number of correct trials achieved in each colour memory condition for each of the groups is shown in Table 2. Although there was little difference between the groups on memory for non-focal colours, the control group were more successful in remembering focal colours compared to non-focal colours, and compared to the group with Down syndrome. Examination of individual data showed that twelve of the sixteen control children remembered focal colours more successfully than non-focal colours, with the differences between scores for the two conditions varying from 1 to 4 items (mode = 2). The other four control children remembered the two classes of colours equally well. Although ten individuals with Down syndrome also had better focal than non-focal colour memory scores, the difference was just one tile in most cases, and four individuals showed a reversed effect and remembered one more non-focal than focal colours.

Table 2 about here

A two factor ANOVA investigated the main effect of group and the repeated measures factor of type of colour on colour memory scores. The group effect was not significant ($F(1, 30)=3.02$; $p=.093$), but the type of colour presented produced a significant main effect ($F(1, 30)=21.47$; $p<.0001$) (mean for focal colours = 3.29; mean for non-focal colours = 2.1), and there was also a significant interaction between group and stimulus colour type ($F(1, 30)=4.35$; $p=.046$). Investigation of this interaction showed that only focal colours produced a statistically significant difference in performance between the two groups ($t(30)=-2.19$; $p=.037$). The other way to look at this interaction was that only the control children showed a significant difference in memory for focal and non-focal colours (DS: $t(15)=1.65$; $p=0.119$; Control: $t(15)=5.27$; $p<0.0001$). The main analysis was repeated using actual spans rather than test scores, with very similar results (Group: $F(1,30)=3.89$; $p=0.58$; Colour set: $F(1,30)=10.29$; $p=0.003$; Group x Colour: $F(1,30)=5.25$; $p=0.029$).

Colour knowledge tasks

Colour knowledge was assessed on the assumption that this would influence memory performance. Table 3 shows the mean numbers of colours listed by each group, numbers of colours identified, and numbers of colours correctly pointed to in the colour comprehension task.

Table 3 about here

Independent t-tests to compare performance for the two groups on each of these tasks showed that there were no significant differences between the groups in any of these aspects of colour knowledge. Reliability Analysis of the three knowledge test results indicated a Cronbach's alpha of 0.77 for the group with Down syndrome and 0.67 for the control group; scores for the three tests were summed and averaged to give a composite colour knowledge score.

Correlations

Correlations were calculated between CA, nonverbal ability, receptive vocabulary, colour knowledge and all memory measures (see Table 4).

Table 4 about here

For control children, colour knowledge was correlated with age and with verbal and non-verbal mental age. When age was partialled out of the correlation, no significant relationships with Ravens or BPVS scores remained (r(13)=0.35, n.s.), suggesting that growth in colour knowledge depends on maturation and experience rather than on cognitive abilities. Colour knowledge was significantly related to focal colour memory in this group, but not to nonfocal colour memory. The difference in the size of these these correlations just missed significance (t(13)=1.65; p>0.05) (Hotelling, 1940). For children with Down syndrome, there was also a significant correlation between colour knowledge and focal colour memory but the correlation between colour knowledge and nonfocal colour memory was virtually zero. Only for control children was there a significant correlation between scores obtained under the two colour memory conditions. This is most probably because of different patterns of performance for each group; whereas the majority of controls exhibited superior focal to nonfocal colour memory, the group with Down syndrome had more mixed results with some individuals showing the opposite pattern in their results.

If participants were using a verbal strategy to remember focal colours, some relationship between digit span scores and focal colour memory scores might be expected, based on a possible common task dependence on processes in the articulatory rehearsal loop. Digit span as well as Corsi span was significantly related to focal colour memory for control children, and there was no significant difference in the sizes of the two correlations (t(13)=0.37, n.s.). When the contribution of visuo-spatial memory abilities to colour memory was controlled by partialling out Corsi scores, the relationship between digit span and focal colour memory remained significant (r (13) = 0.51, p=0.05), suggesting that although the number of colour memory trials was limited to two at each level, that this has produced a reasonably reliable estimate of colour memory. It also suggests that the control children may be using a verbal rehearsal strategy for remembering the focal colours.

For the group with Down syndrome, Table 4 shows that only the relationship between Corsi scores and focal colour memory was significant. While this relationship could suggest the use of visual memory in completing the colour task, there is not such a strong argument for this assumption. First, because the size of this correlation did not differ significantly from that of the correlation between digit span and focal colour memory ($t(13)=0.57$, n.s.), and also because there was less correspondence in task demands for the Corsi and colour memory tasks.

Discussion

This study has shown that, despite comparable levels of colour knowledge, and significantly better Corsi blocks performance than the control group, individuals with Down syndrome did not demonstrate an advantage for colour memory. Focal colours were remembered significantly more successfully than non-focal colours by controls, but the two classes of colour were remembered equally well by children with Down syndrome. Focal colours were remembered significantly more successfully by controls than by individuals with Down syndrome, but both groups produced very similar results in the non-focal colour memory condition.

The comparison of digit span with Corsi span confirms a pattern of performance in Down syndrome that is now fairly well established. Although previous research has not always reported group differences in these tasks as statistically significant, the effects in this experiment provide evidence for a deficit in the phonological loop component of working memory in Down syndrome combined with a strength in visuo-spatial memory. However, although individuals with Down syndrome scored significantly more than controls on the Corsi task, there was no evidence for superior colour memory performance over control children. This result could be accounted for in terms of the different demands of the two tasks. The Corsi blocks test offers stimuli which integrate visual and spatial components while the colour memory task does not provide similar spatial information. These results might suggest that it is the spatial component which contributes to the superior Corsi performance of the group with Down syndrome. This could also explain the more marked contrast between the tasks found in the current research compared to earlier work which has presented a computerised version of the Corsi test (e.g. Jarrold & Baddeley, 1997) where the arm movements of the experimenter are not available as an additional spatial memory cue.

It was interesting that the children and adolescents with Down syndrome showed the same levels of colour knowledge as the control children. Reliable colour naming may be acquired relatively late in normal development (e.g. Bornstein, 1985), and so it would not have been surprising to find it to be specifically delayed in children with Down syndrome. Possibly, the normal tendency to late acquisition of colour terms is offset by the greater chronological age of these individuals and the additional world experience that this has provided. However, it is curious that world experience does not prevent specific delays in other abstract domains. For example, spatial terms may be acquired later than by typically developing children matched on receptive vocabulary (Fayesse, 1997; Laws & Lawrence, 2001), and there are also specific delays in the acquisition of number concepts (Gelman & Cohen, 1988; Nye, Clibbens & Bird, 1995). This suggests that associating a name with a sensory experience, as in learning colour terms, is easier for children with Down syndrome than learning the terms for more abstract rule-based concepts such as number.

The main aim of this study was to investigate whether there was evidence for an advantage in visual memory for individuals with Down syndrome under conditions which placed no demand on hearing or encoding of auditory stimuli, and where the memory strategies available for task completion were constrained by the nature of the task. Given a view of short term memory development as the growth of flexible strategies for the retention and recall of information, it would not be surprising if individuals with Down syndrome were to develop visual memory skills to compensate for the verbal memory difficulties associated with the syndrome. However, this experiment produced no evidence for this in the critical condition comparing memory for non-focal colour stimuli with that of the control group. Although this result provides evidence for a relative sparing of visual memory, in that the participants performed at the same level as typically developing children of the same mental age, there was no suggestion that visual memory skills advanced beyond that expected for mental age.

Performance on the focal colour memory task provided evidence for an impairment in the phonological loop component of working memory to add to the body of evidence from earlier research. Whereas control children produced significantly higher scores for remembering focal colours compared to non-focal colours, there was no such difference for the group with Down syndrome. It was assumed that the control children's performance was due to the adoption of a verbal recoding strategy for remembering the focal colours on the basis that these colours were more codeable, and the fact that focal colour memory was significantly related to digit span. This relationship may reflect the reliance of both tests on the articulatory rehearsal component of the phonological loop - for rehearsing the digits in the digit span task, and for recoding visual stimuli to a verbal code in the colour memory task. The main importance of these results is that they raise some interesting questions in connection with previous research both for the group with Down syndrome and for the control group.

The ages of the control children in the experiment ranged from about 3 to 7 years and, on the basis of much earlier research on young children’s use of memory strategies (e.g. Hitch et al , 1988), there would be some justification for expecting that at least the youngest children in this group would not use verbal recoding. However, twelve of the sixteen control children produced higher focal than non-focal colour memory scores, including some of the youngest children in the sample. If recoding of the focal colours to a verbal representation accounts for the more successful focal colour memory, then the results suggest that these children were using this strategy. This supports Palmer’s (2000) argument that a verbal code is available to children considerably younger than 7 years of age. Whether they are able to exploit it may depend on the specific experimental stimuli and procedures adopted. Since the present experiment offered colours, rather than the line drawings of familiar objects used in previous research, it is possible that this in itself could account for the more general appearance of verbal recoding in this relatively young group. It is also possible that the strength of the effect was influenced by the relatively long processing time available to the children. This allowed time not only to name the colours on presentation but also to rehearse the names before selecting the response tiles. An alternative account of the difference in control children's memory under the two colour conditions could be in terms of the perceptual characteristics of the colours. However, if this were so, it is difficult to see why the group with Down syndrome should not also have found focal colours much easier to remember.

The performance of the group with Down syndrome contributes some further information about the locus of the phonological memory impairment in Down syndrome. Previous explanations for the impairment have included the articulation difficulties associated with the syndrome, a lack of spontaneous rehearsal or general auditory processing problems. Although poor phonological memory in young typically developing children is related to slower speech rates which reduce the number of words that can be accommodated by the articulatory rehearsal mechanism (e.g. Hulme, Thomson, Muir & Lawrence, 1984), articulation rate has been ruled out as an explanation for memory impairment in people with Down syndrome, despite their speech difficulties (Hulme & Mackenzie, 1992; Jarrold, et al, 2000).

The failure to adopt subvocal rehearsal as the primary explanation for the phonological memory deficit has also recently been called into question (Jarrold et al, 2000). The marker for rehearsal activity, in normal developmental research as well as in studies of atypical populations, has been the word length effect (Baddeley, Thomson & Buchanan, 1975). If more short words than long words are recalled, this has been taken as an indication of articulatory rehearsal activity since more short words can be accommodated within the limited capacity of the loop. However, it has been pointed out that the word length effect could also be due to output effects (Cowan, et al, 1992; Henry, 1991; Jarrold, et al, 2000) since the longer it takes to output the first word or words in a serial recall task, the more difficult it becomes to recall later words in the list as they are more likely to fade. Jarrold, et al (2000) suggested that neither the group with Down syndrome that they studied, nor control groups of individuals with moderate learning difficulties or younger typically developing children, could be using rehearsal because the word length effect was removed when a probed recall procedure was used that required no verbal output. They noted that although rehearsal played no part in task performance, there nevertheless remained a deficit for the group with Down syndrome, primarily associated with early items. As a consequence, Jarrold et al argue that the memory deficit in Down syndrome must either be related to the capacity of the phonological store or to processes outside the memory system, such as hearing.

Although many individuals with Down syndrome have hearing difficulties (Davies, 1996), previous research has failed to establish an association between these and poor verbal short-term memory (Jarrold & Baddeley, 1997; Jarrold et al, 2000; Marcell, 1995; Marcell & Cohen, 1992). Since the focal colour memory condition in the current experiment made no demands on auditory encoding, and yet produced a significant group difference, it also suggests that the memory impairment is not related to auditory processing. The most likely explanation for results in the focal colour condition would seem to be in terms of a lack of verbal recoding by the group with Down syndrome, since no auditory encoding was required, there was no verbal output demand and, since non-focal colour memory was the same in both groups, the difference between the groups' focal colour memory could not be explained by superior visual memory in the control group.

An alternative explanation is that verbal recoding is attempted by individuals with Down syndrome but that articulation rates, even for 'inner speech', are slow and result in ineffective representations. This could have been investigated by measuring overt articulation of colour names although, as mentioned earlier, previous research with individuals with Down syndrome has failed to find a relationship between articulation rate and span for auditorily presented material (Hulme & Mackenzie, 1992; Jarrold, et al, 2000). Another explanation could be in terms of a possible deficit in the long-term memory representation of the colour domain in individuals with Down syndrome. However, the fact that their performance was equal to that of the typically developing children on the tests of colour listing, colour identification and colour comprehension probably suggests that there is no essential difference between the groups in this respect. Finally, it is also possible that the problem lies not necessarily in verbal recoding but in a failure to maintain the colour names by rehearsal while a response was selected. Although the experiment was not designed to distinguish between storage and maintenance explanations for short term memory impairment in Down syndrome, these results do suggest it may be premature to reject the notion that a lack of rehearsal is a factor in the impairment.

In summary, this experiment provided further evidence for a deficit in verbal short term memory in children with Down syndrome, combined with a relative strength in visuo-spatial memory. Despite this strength, and the fact that the children had the same levels of colour knowledge as controls, there was no indication of any advantage in visual memory. The difference in the patterns of results for Corsi and colour memory tasks could suggest that it is the spatial component of the Corsi task which leads to the advantage shown by individuals with Down syndrome on this test. The control children appeared to use verbal recoding as a strategy for remembering the more codeable focal colours, but may also use rehearsal of the colour names to maintain verbal representations while responses are selected. These strategies did not seem to be available to the children with Down syndrome. Since verbal recoding depends on the articulatory rehearsal component of the phonological loop, these results suggest that this may be one locus of the phonological memory impairment characteristic of Down syndrome. However, this should be considered in relation to recent research which tends to suggest that it is the phonological store which is the problem (Jarrold et al, 2000). The experiment presented here offered no direct information on the functioning of the phonological store but, given this conflicting evidence, further research is needed to establish which of these components do account for the impairment or, indeed, whether there are problems associated with both of them.

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Table 1: Mean (sd) CA, BPVS, Ravens, verbal fluency and memory scores for the two groups of children

	Down Syndrome (N=16)	Typically Developing (N=16)
CA (months)	140.31 (41.35)	54.44 (13.45)
BPVS II score	40.00 (16.03)	40.00 (16.08)
BPVS age equivalent (months)	48.38 (17.27)	48.43 (17.25)
Ravens score*	11.00 (5.23)	14.00 (4.02)
Verbal fluency	20.93 (10.96)	16.44 (8.25)
Digit score	1.88 (1.31)	4.50 (2.13)
Corsi score	3.94 (1.24)	2.44 (0.81)

*It was not possible to calculate age equivalent scores for some of the lower scoring children. Mean raw scores were equivalent to approximately 4 and 5 years for the group with Down syndrome and controls respectively.

Table 2: Mean number of correct trials for focal and non-focal colour conditions for each group, and mean memory span for each colour condition

	Down syndrome (N=16)		Typical Development (N=16)	
	Mean (sd)	Range	Mean (sd)	Range
Focal colour trials	2.69 (1.4)	0-5	3.94 (1.81)	1-7
Focal span (max 8)	1.69 (0.95)	0-3	2.63 (1.15)	1-5
Non-focal colours trials	2.00 (1.03)	0-4	2.13 (1.02)	1-4
Non-focal span (max 8)	1.50 (0.73)	0-4	1.50 (0.63)	1-3

Table 3: Means (sd) for colour knowledge measures for each group

	Down syndrome (N=16)	Typical development (N=16)
Colour listing	7.56 (2.53)	6.69 (3.20)
Focal colour naming (max 11)	9.06 (2.38)	9.12 (1.78)
Non-focal colour naming (max 8)	7.44 (0.96)	7.06 (1.12)
Focal colour comprehension (max 11)	9.00 (2.99)	9.87 (1.67)

Table 4: Correlations among all measures

a) Down syndrome (N=16)

	1.	2.	3.	4.	5.	6.	7.
1. Age (months)	-						
2. Ravens	0.45	-					
3. BPVS II	0.54*	0.53*	-				
4. Digit scores	0.13	0.07	0.04	-			
5. Corsi scores	0.28	0.65**	0.45	0.45	-		
6. Colour knowledge	0.50*	0.49	0.47	0.41	0.64**	-	
7. Focal colour memory	0.40	0.49	0.53*	0.31	0.49	0.73**	-
8. Nfocal colour memory	0.45	0.01	0.27	-0.05	-0.05	0.09	0.09

-

a) Typical development (N=16)

	1.	2.	3.	4.	5.	6.	
1. Age (months)	-						
2. Ravens	0.71**	-					
3. BPVS II	0.76**	0.88***	-				
4. Digit scores	0.73**	0.76**	0.66**	-			
5. Corsi scores	0.49	0.53*	0.53*	0.33	-		
6. Colour knowledge	0.59*	0.62*	0.63**	0.66**	0.25	-	
7. Focal colour memory	0.58*	0.74**	0.72**	0.59*	0.52*	0.56*	-
8. Nfocal colour memory	0.40	0.57*	0.32	0.43	0.33	0.29	0.65**

*p<.05; **p<.01;***p<.001

Appendix: The colour stimuli used in the experiment

The colour stimuli used in this study were two small subsets of the 219 colours supplied in paper form by the Color-Aid Corporation and classified according to the Ostwald colour solid (see Foss, Nickerson & Granville, 1944; Smith, 1965). The Color-Aid papers provide a convenient way of obtaining samples that are a reasonable selection of all possible colours. For further information and an explanation of these see Appendix in Laws et al, 1995. Table A1 lists the Color-Aid designation for each of the stimulus colours used, the names of the focal colours, and gives some idea of the non-focal colours used.

Table A1

Focal colours	Non-focal colours
Color-Aid code (colour name)	Color-Aid code (colour name range)
RO hue (red)	ORO T4 ('orange-pink')
Y hue (yellow)	Y S1 ('yellow-green')
YG hue (green)	Maroon ('red-purple')
B hue (blue)	G T4 ('light green-blue')
O hue (orange)	YOY T4 ('yellow-orange')
O S3 (brown)	ORO S3 ('pink-grey')
BV T1 (purple)	BG Hue ('dark blue-green')
R T4 (pink)	Y S2 ('green-brown')
GRAY 4 (grey)	
BLACK (black)	
WHITE (white)	