Short-term memory in Down syndrome

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OVERVIEW

Individuals with Down syndrome consistently show relatively poor performance on tests of verbal short-term memory such as digit span tasks. However, poor performance on such tasks does not necessarily imply that individuals suffer from a fundamental impairment to some verbal short-term system, particularly given that hearing difficulties, speech production problems, and language delay are also associated with the condition and would be expected to adversely affect task performance. In fact the work reviewed here suggests that although these other factors may contribute to the low levels of performance typically observed on such tests by individuals with Down syndrome, there is also evidence for a reduction of verbal short-term memory capacity. The implications of this deficit for the development of vocabulary skills in Down syndrome are discussed, although the data currently do not clearly support the suggestion that vocabulary in Down syndrome is constrained solely by individuals’ relatively poor verbal short-term memory.
BACKGROUND TO DOWN SYNDROME

Down syndrome owes its name to J. Langdon Down, who published a description of the condition in the mid 19th century (Langdon Down, 1866), but there is clear evidence that the condition was prevalent prior to this time (Stratford, 1996). It is a genetic condition, caused by a triplication of the 21st chromosome (trisonmy 21). Trisonmy 21 is, in fact, not the only form of trisonmy that occurs in humans. However, the fact that chromosome 21 is the smallest of our chromosomes means that the extra loading of genes associated with Down syndrome has less impact than in other triplications, increasing the viability of the individual. Indeed, according to some estimates, Down syndrome is the most common single organic cause of learning disability, with a prevalence of approximately 5 per 10,000 live births (Steele & Stratford, 1995). Although pre-natal screening for Down syndrome is increasingly common in developed countries, any reduction in the birth rate as a result appears to be offset in recent years by a trend for mothers to have children later in life coupled with the fact that the incidence of Down syndrome rises steeply with maternal age (Steele, 1996).

Down syndrome is associated with a number of physiological features, which include a characteristic physiognomy, heart defects, hearing difficulties and speech-motor problems often caused by the presence of cleft palate and enlarged tongue size relative to the oral cavity. In addition, individuals with Down syndrome typically suffer from some degree of mental retardation. As little as thirty years ago (and arguably more recently than this) expectations and outcomes for individuals with Down syndrome were relatively bleak. More recently the advent of early intervention programmes, more sophisticated medical care, and higher expectations in general, have led to improvements in the educational levels attained by children with Down syndrome. A number of individuals are educated in a mainstream setting, at least over primary school years, and some can show near to age-appropriate levels
of ability. Nevertheless, in general individuals with Down syndrome do suffer from some form of intellectual delay (Carr, 1985).

**IMPAIRED VERBAL SHORT-TERM MEMORY PERFORMANCE IN DOWN SYNDROME**

Given these general intellectual difficulties, it is perhaps unsurprising that early studies showed that individuals with Down syndrome had poor short-term memory skills. For example, Rohr and Burr (1978) found that a sample of children and teenagers with Down syndrome had auditory and visual memory scores that fell below the 5-years age equivalent level on the Illinois Test of Psycholinguistic Development (ITPA; Kirk, McCarthy, & Kirk, 1968) (see also Burr & Rohr, 1978). Of more interest is whether memory performance is delayed in Down syndrome relative to individuals’ general level of intellectual abilities; or in other words, whether memory performance in Down syndrome is specifically impaired. In fact studies using tests such as the ITPA or the Stanford-Binet test battery (Thorndike, Hagen, & Sattler, 1986) showed that the performance of individuals with Down syndrome on visual memory subtests was in line with general intellectual abilities, but that their performance on the verbal memory subtasks was considerably poorer (Bilovsky & Share, 1965; Bower & Hayes, 1994; Burr & Rohr, 1978; Kay-Raining Bird & Chapman, 1994; Rohr & Burr, 1978; see also Marcell & Armstrong, 1982). The tasks used to assess verbal memory in these studies were all versions of digit span, and consequently these papers provide preliminary evidence of a particular problem in verbal short-term memory in Down syndrome.

However, as Marcell and Armstrong (1982) pointed out, it is not clear that test batteries such as the ITPA provide a proper comparison of verbal and visuo-spatial short-term memory, because the visual memory subtests do not tap immediate serial recall of visuo-spatial information in a manner analogous to digit span in the verbal domain. In the ITPA
visual memory subtest, participants are shown an abstract design and then have to recreate that design by arranging tiles into the correct configuration. Similarly, the nonverbal ‘bead memory’ subtest of the Stanford-Binet test battery involves the recreation of a visual pattern with appropriate props.

In an attempt to counter this concern, and to provide a more meaningful comparison of verbal and visuo-spatial short-term memory performance in Down syndrome, Marcell and Armstrong (1982) explored the magnitude of the modality effect in immediate serial recall among typically developing children and individuals with Down syndrome. That is, they compared short-term memory for digits that were presented either auditorily or visually. These authors showed that, while typically developing children showed superior performance for auditorily rather than visually presented digits, in line with previous research (Dilley & Paivio, 1968), individuals with Down syndrome showed no such advantage. Similarly, McDade and Adler (1982) found that their sample of children with Down syndrome showed impaired recall of auditorily presented digits, but unimpaired recall of visually presented digits relative to mental age matched controls. One potential concern about this approach is that standard models of working memory (e.g., Baddeley, 1986) state that verbal information is stored in verbal short-term memory regardless of its mode of presentation; for example adults show relatively poor recall of phonologically confusable lists that are presented visually (Conrad, 1964). Given this, manipulations of presentation modality do not tap fundamentally different storage systems among adults. However, there is considerable evidence that young children aged less than 7 do not spontaneously recode visually presented verbal material into a phonological form (Conrad, 1971; Hitch, Halliday, Dodd, & Littler, 1989; Hitch, Halliday, Schaaftstal, & Schraagen, 1988). Consequently, a modality manipulation presented to individuals aged less than 7, or functioning below an age-
equivalent level of 7 as was the case for Marcell and Armstrong’s Down syndrome sample, may well provide an appropriate comparison of verbal and visuo-spatial short-term memory.

A recent and elegant extension of this line of research was carried out by Laws (2002) who examined memory for ‘focal’ and ‘non-focal’ colours among individuals with Down syndrome and controls. She classed focal colours as those that were readily labelable, such as ‘red’, ‘yellow’ or ‘green’ and non-focal colours as those that were harder to label due to being non-primary (e.g., a ‘dark blue-green’ colour), and presented sequences of these items which participants then had to recall in serial order by pointing to a duplicate response array. Laws found that individuals with Down syndrome were unimpaired relative to mental age matched controls in their ability to recall non-focal colours, but showed a deficit in memory for focal colours. She argued that this reflected unimpaired visual short-term memory in Down syndrome, but impaired verbal memory for colours that could be named. Of course, this implies that participants in this instance were able to recode the visually presented focal colours into verbal labels, contrary to the suggestions made above. Indeed, among controls only, memory was superior for focal as opposed to non-focal colours despite the fact that these individuals were all younger than 7 years of age.

Although these data are clearly suggestive of impaired verbal short-term memory performance in Down syndrome, relative to levels of visuo-spatial short-term memory performance, they are clearly open to concerns about the extent to which visually presented material is relableable into a phonological form. Consequently, arguably stronger evidence for this dissociation comes from studies that have contrasted digit or word span tasks with more ‘traditional’ measures of visuo-spatial short-term memory. One such task is the Corsi span test in which participants watch as an experimenter taps a sequence of blocks from among a set of nine possible locations, before having to reproduce the sequence themselves.
In many ways this provides a visuo-spatial analogue of a digit span task, and consequently a direct comparison between these two tests is particularly informative.

Studies that have contrasted Corsi and digit memory in individuals with Down syndrome and appropriate comparison groups have consistently shown unimpaired Corsi performance among Down syndrome groups (Brock & Jarrold, 2005; Jarrold & Baddeley, 1997; Jarrold, Baddeley, & Hewes, 1999; Jarrold, Baddeley, & Phillips, 2002; Laws, 2002; Numminen, Service, Ahonen, & Ruoppila, 2001; Vicari, Carlesimo, & Caltagirone, 1995). In addition, in all bar one of these studies (Vicari et al., 1995) an interaction was indicated by the data, reflecting impaired performance on the digit task among the Down syndrome participants. This clearly supports the claim for a specific deficit in short-term memory for verbal material, but there remains at least one concern as to the comparability of even this pair of tasks. In typical digit span tests, one avoids presenting lists that consist of obvious number ‘patterns’ (e.g., ‘1, 2, 3, 4’, ‘8, 6, 4, 2’), and consequently individuals need to retain both the items in the list and the order in which they were presented. In contrast, although Corsi span tasks do call for recall of item location in correct serial order, there is some evidence that participants typically remember the shape traced out by the path connecting successive locations in the list. For example, Corsi recall is typically poorer when the traced path crosses over itself than when it describes a single figure without crossing (Kemps, 2001) suggesting that individuals might rely less on discrete representations of every location that are held in appropriate order, and more on a representation of the general path shape. If so, then the relatively strong performance of individuals with Down syndrome on this task might reflect good recall of pattern and form (cf. Stratford, & Metcalf, 1982) rather than recall of serial order of the kind involved in digit span; an issue that we are exploring in our current work. Nevertheless, the existing evidence from studies of Corsi recall, coupled with the data from studies of the effect of modality of presentation on verbal recall and Laws’ colour
memory experiment, does suggest that individuals with Down syndrome have a specific

A related question is whether this apparent deficit in Down syndrome is specific to
verbal short-term as opposed to verbal long-term memory. There is evidence that individuals
with Down syndrome showed impaired recall on list learning paradigms in which list of
words are repeatedly presented for successive recall in order to test long-term verbal learning
(Carlesimo, Marotta, & Vicari, 1997; Nichols et al., 2004; Pennington, Moon, Edgin,
Stedron, & Nadel, 2003 see also Vicari, Bellucci, & Carlesimo, 2000). However, these tasks
tap recall of information that is learnt over a series of immediate recall trials, and
consequently learning in this procedure may depend to some extent on verbal short-term
memory skills. Indeed, Carlesimo et al. (1997) found poorer list learning among individuals
with Down syndrome than controls, but comparable forgetting rates over time among these
groups given the level of learning obtained. In addition, in our own work we have looked at
individuals’ ability to learn long-term verbal labels using the Names subtest of the Doors and
Pictures test (Baddeley, Emslie, & Nimmo-Smith, 1984). In this task participants are
required to learn the names of four individuals in response to being shown their photograph.
Among our sample of individuals with Down syndrome, performance on this test was no
poorer than one would expect given individuals’ general levels of verbal ability (Jarrold,

Carlesimo et al. (1997) did also report poorer prose recall among individuals with
Down syndrome (cf. Wilson & Ivani-Chalian, 1995; though see also Seung & Chapman,
2003), a finding not so open to concerns about the involvement of short-term memory in list
learning. However, in relatively open-ended tasks such as this it is possible that impaired
recall reflects poorer organisational strategies or levels of motivation rather than impaired
mnemonic skills; certainly there is evidence of a reduced motivation for task compliance in
Down syndrome (Wishart, 1993). Consequently, although there is some evidence of verbal long-term memory deficits associated with Down syndrome, and more work in this area is certainly needed, our current view is that this is considerably weaker than the corresponding evidence for verbal short-term memory problems in Down syndrome.

**DO THESE DEFICITS EXTEND TO WORKING MEMORY TASKS?**

The distinction between short-term and working memory is not always clearly drawn, after all Baddeley’s (1986) ‘working memory’ model readily accommodates performance on ‘short-term memory’ tasks of the form described above. In our research we restrict the term ‘short-term memory’ to situations where information has to be maintained over the short-term, without any obvious manipulation of that material and in the absence of any other distracting activity; a digit span task would be an example of such a situation. In line with others (e.g., Daneman & Merikle, 1986; Engle, Tuholski, Laughlin, & Conway, 1999) we would argue that working memory involves a similar degree of maintenance or storage of information, but also requires the manipulation or processing of information that can lead to more rapid forgetting of to-be-remembered material. For example, in ‘complex span’ working memory tasks individuals are typically presented with a series of processing episodes which they have to complete, and which often provide a to-be-remembered item of information; in reading span tasks (e.g., Daneman & Carpenter, 1980) individuals read and make decisions about a series of sentences before recalling the final word of each sentence, in counting span tasks (e.g., Case, Kurland & Goldberg, 1982) individuals count the dots on a series of cards and remember these count totals for subsequent serial recall. Although such measures clearly capture something more than ‘simple span’ short-term memory tasks such as digit span (Engle, 2002), they share with them the need to maintain information in correct serial order. Consequently, one might view such tasks as more complex extensions and variants of short-term memory procedures (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Engle
et al., 1999). As a result, one would expect any individual to perform less well in absolute terms on a complex span task (e.g., reading or counting span) than a corresponding simple span version (e.g., word or digit span).

However, in the only two studies that, to our knowledge, have presented verbal complex span tasks to individuals with Down syndrome, performance was found to be unimpaired relative to controls (Numminen et al., 2001; Pennington et al., 2003). This surprising result might reflect the fact that individuals with Down syndrome carried out the processing aspects of these working memory task more rapidly than controls, and so offset a deficit in recall by reducing the time over which items in memory were subject to decay (cf. Towse & Hitch, 1995). Alternatively, the lack of group effects in these studies may reflect floor effects on performance; indeed, among the individuals with Down syndrome assessed by Numminen et al. (2001) average reading span scores were less than 1. Certainly, to the extent that one could accurately measure verbal working memory in Down syndrome, one would expect it to be impaired to a comparable extent as verbal short-term memory. Indeed, given evidence that the neurophysiological signs of Alzheimer’s disease are present in individuals with Down syndrome at an early age (Wisniewski & Silverman, 1996) one might predict additional impairments in aspects of working memory such as dual task coordination (cf. Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986) among older individuals with Down syndrome.

DO VERBAL SHORT-TERM MEMORY DEFICITS REFLECT PROBLEMS OF HEARING AND SPEECH?

The above review suggests that individuals with Down syndrome perform particularly poorly on tests of verbal short-term memory; a conclusion entirely in line with the view that verbal short-term memory is specifically impaired in the condition. However, this conclusion is only warranted if it be can be shown that poor performance does not result from some other
deficit associated with Down syndrome that particularly affects tasks such as digit span. In fact there are a number of such alternative explanations of poor task performance that follow from the fact that verbal short-term memory tasks are typically presented auditorily, and require spoken serial recall. Most notably, given that individuals with Down syndrome tend to have hearing deficits (e.g., Dahle & McCollister, 1986) and speech production problems (e.g., Dodd & Thompson, 2001) one might expect them to particularly struggle on such tasks regardless of the quality of their underlying memory abilities. Obviously, if an individual cannot hear a presented item it is unreasonable to expect them to be able to recall that item. Similarly, speech production difficulties could lead to imperfect and hard-to-interpret responses at recall. In addition, slowed verbal responding to a task will lead to a greater opportunity for time-based forgetting of to-be-produced items (cf. Cowan et al., 1992).

Studies have tended to address these concerns in two ways. One approach has been to measure the degree of hearing loss and speech production problems shown by individuals with Down syndrome, and the extent to which these correlate with levels of verbal short-term memory performance. Cairns and Jarrold (in press) showed that individuals with Down syndrome were impaired relative to controls on a test of nonword repetition, a task that many argue taps verbal short-term memory but which is certainly also affected by speech discrimination and production skills. Indeed, these individuals did have significantly poorer speech production abilities, and somewhat poorer speech discrimination skills, than controls. Nevertheless, neither of these measures was reliably related to nonword repetition score in this sample. In contrast, Laws and Gunn (2004) reported a trend for nonword repetition ability among individuals with Down syndrome to be related to individuals’ level of hearing loss.

While one might well expect hearing and speech production problems to be particularly detrimental to nonword repetition, where unfamiliar items have to be identified and repeated,
one might expect less of an effect on performance on more standard digit and word span tasks where to-be-remembered items are more familiar and discriminable (cf. Briscoe, Bishop, & Norbury, 2001). Indeed, there is even less evidence of correlations between levels of hearing ability and digit span among individuals with Down syndrome. Both Marcell and Cohen (1992) and Jarrold and Baddeley (1997) found no evidence of a reliable relationship between these measures. However, Marcell and Cohen did find an association between hearing thresholds and ability to identify speech that was masked by noise, and it may well be the case that subtle difficulties in item identification that are not picked up by more standard measures such as pure tone audiometry do affect encoding of verbal information in verbal short-term memory tasks in Down syndrome. Having said this, Brock and Jarrold (2005) found that individuals with Down syndrome did not differ from controls in the time taken to identify digits, despite showing poorer short-term memory for them.

A second way of addressing the concern about the influence of hearing and speech problems on verbal short-term memory in Down syndrome has been to manipulate the type of task employed to minimise these potentially confounding factors. Jarrold, Baddeley, and Phillips (2002) examined the impact of hearing loss on performance by providing visual support when presenting to-be-remembered verbal information. As discussed above, it is arguable whether words or digits that are only presented visually are stored in a phonological code by individuals of a developmental level less than 7 years, however, if items are presented both visually and auditorily then the visual support may serve to remove any confusion as to the identity of the to-be-remembered phonological trace. Jarrold et al. (2002) did find that providing visual support improved digit spans among individuals with Down syndrome, but it did not remove the deficit in performance relative to controls.

Other manipulations have attempted to reduce or eliminate the need for individuals to produce a full spoken output in response to a verbal short-term memory task. Jarrold et al.
(2000) employed a probed recall procedure in which individuals were asked to provide the identity of only one item in a 3-item list, thereby removing the need for a serial spoken response (see also Purser & Jarrod, in press). Although individuals with Down syndrome were unimpaired on trials when either of the final two items in the list was probed, they showed impaired performance on the first item in each list, suggesting that reducing output demands did not fully remove the memory deficit. Other studies have employed recognition procedures in which participants simply have to state whether a second list is identical to, or differs from, a target list of verbal items. Individuals with Down syndrome remain impaired on such tasks regardless of whether recognition of order (Jarrold et al., 2002) or item information is required (Brock & Jarrold, 2004). Finally, both Marcell and Weeks (1988) and Brock and Jarrold (2005) employed reconstruction of order tasks in which participants were presented with visual images of the verbal items presented auditorily in a list, and had to indicate the serial order in which they were presented by a non-verbal pointing response. In both cases individuals with Down syndrome were impaired relative to controls despite the absence of a verbal spoken response.

In summary, it is entirely possible that perceptual abnormalities and speech production problems exacerbate the difficulties experienced by individuals with Down syndrome on tests of verbal short-term memory. Indeed, it may be that individuals show such marked impairments on traditional verbal short-term memory measures precisely because these tasks combine the need to encode, remember and reproduce verbal information, all of which may be problematic in Down syndrome. However, the results of the above studies strongly suggest that verbal short-term memory difficulties in Down syndrome cannot be wholly, or even primarily, accounted for by these perceptual and speech production difficulties.

DO VERBAL SHORT-TERM MEMORY DEFICITS REFLECT DEFICIENT LINGUISTIC KNOWLEDGE?
One other possible explanation of poor verbal short-term memory performance in Down syndrome follows from evidence that individuals’ scores on short-term memory tasks are typically affected by their familiarity with the to-be-remembered material. So, for example, both adults and children typically show reliably higher short-term memory spans for words than for nonwords (Brener, 1940; Hulme, Maughan, & Brown, 1991; Roodenrys, Hulme & Brown, 1993). Importantly, this effect appears not to be mediated by differences in the underlying memorability of these items (Hulme et al., 1991; Roodenrys et al., 1993), but rather is thought to reflect the fact that long-term linguistic knowledge can be used by participants to recreate degraded traces. This process of ‘redintegration’ is clearly more effective for word than for non-word stimuli, as individuals’ lexical knowledge allows them to make a ‘best guess’ as to the possible identity of degraded word traces. Nevertheless, there is clear evidence that nonword recall is also influenced by individuals’ familiarity with the stimuli as indexed by the similarity of these nonwords to existing known words (e.g., Gathercole, 1995; Roodenrys & Hinton, 2002; Thorn & Gathercole, 2001). Given this, and the fact that the language skills of individuals with Down syndrome tend to be poorer than their other abilities (e.g., Chapman, 1997; Fowler, 1990), it is possible that poor verbal short-term memory performance is a secondary consequence of individuals’ relatively impoverished language knowledge (cf. Hulme & Roodenrys, 1995).

In fact, three lines of evidence count against this suggestion. First, individuals with Down syndrome show impaired verbal short-term memory performance even when matched to controls for level of receptive vocabulary (Brock & Jarrold, 2005; Jarrold & Baddeley, 1997; Jarrold et al., 2002; Laws, 2002); and although the assessment of receptive vocabulary does not give a fully comprehensive index of language familiarity, one would certainly expect it to provide a reasonable estimate of linguistic knowledge. Second, there is evidence that the benefits of lexical knowledge on verbal short-term memory only operate in recall
tasks where individuals have to re-produce to-be-remembered items, presumably because redintegrative processes operate to enable recall of partially degraded items. In contrast, lexicality effects – superior memory for words than nonwords – are less marked in paradigms that test recognition of order memory where item information is re-presented at test (Brock, McCormack, & Boucher, 2005; Gathercole, Pickering, Hall, & Peaker, 2001; Thorn, Gathercole, & Frankish, 2002). However, as noted above, individuals with Down syndrome have been found to show impaired verbal short-term memory performance even under these conditions (Brock & Jarrold, 2004, 2005; Jarrold et al., 2002).

Finally, and more directly, studies have examined the magnitude of the lexicality effect shown by individuals with Down syndrome in comparison to that seen among typically developing children. Cairns and Jarrold (in press) showed that although individuals with Down syndrome performed more poorly than typically developing controls on both word and nonword repetition tasks, the magnitude of the lexicality effect, indicated by the difference between these two tasks, was comparable in the two groups. However, these data are somewhat difficult to interpret because of concerns associated with scoring individuals’ recall of nonwords. Consequently, in order to obtain a more sensitive index of lexicality effects, Brock and Jarrold (2004) assessed individuals’ ability to recognise changes to both word and nonword lists using two recognition tasks. In an order memory recognition task, participants were presented with a list of either words or nonwords that was then followed by a second list in which, on 50% of trials, the same items were presented in a different order (e.g., ‘ball, fin, gate’ – ‘ball, gate, fin’; cf. Gathercole et al., 2001; Jarrold et al., 2002). In an item memory recognition task two lists were again presented, but in this case on 50% of trials the second list contained an item change effected by altering one of the phonemes of the initial items (e.g., ‘ball, fin, gate – ‘ball, pin, gate’. Note that lexical status of the altered item was maintained in each case). Participants simply had to decide whether the second list was the
same or different to the first in each case, and a comparison of performance across word and nonword lists provided an estimate of the magnitude of the lexicality effect shown by each group in each task.

Lexicality effects were observed in each task, but were stronger for item than for order memory (cf. Gathercole et al., 2001; Thorn et al., 2002). A direct comparison of the size of this effect in the two groups showed that it was comparable for the order memory task, but that individuals with Down syndrome showed a reliably larger lexicality effect than typically developing individuals on the item memory task. In other words, individuals with Down syndrome performed better than expected on the word version of the task than predicted by their performance on the nonword version. This is the reverse of what one would expect if poor verbal short-term memory performance was a consequence of impoverished linguistic knowledge, which instead would predict a reduced lexicality effect. Brock and Jarrold (2004) suggest that particular problems with memory for nonwords in Down syndrome might reflect difficulties of item identification which are likely to be exacerbated for unfamiliar stimuli (see above), but whatever the case these and the related data reviewed here clearly count against the view that poor verbal short-term memory performance in Down syndrome is simply a reflection of individuals’ generally poor language knowledge.

**INTERPRETING DEFICITS WITHIN THE PHONOLOGICAL LOOP FRAMEWORK**

The fact that the poor verbal short-term memory performance typically shown by individuals with Down syndrome cannot be wholly explained away in terms of problems of hearing, speech production, and linguistic knowledge suggests that the condition really is associated with a fundamental deficit in verbal short-term storage. Consequently, a number of authors have suggested that this deficit might usefully be defined, and further explored, with reference to Baddeley’s (1986) phonological loop model of verbal short-term memory. In fact, the phonological loop is itself a two-component system, consisting of a passive
phonological store in which material is maintained in a phonological code but which is subject to time-based decay, and an articulatory rehearsal process which serves to refresh, and therefore maintain, material in the store. Given this, one might ask whether the problems shown by individuals with Down syndrome on verbal short-term memory tasks reflects a fundamental deficit in either phonological storage or subvocal rehearsal.

In fact, the majority of work in this area has focused on the possibility that Down syndrome might be associated with deficient rehearsal. A number of studies have attempted to improve verbal short-term memory performance in individuals with Down syndrome by providing rehearsal training (Broadley & MacDonald, 1993; Broadley, MacDonald, & Buckley, 1994; Comblain, 1994; Laws, MacDonald, & Buckley, 1996; Laws, MacDonald, Buckley, & Broadley, 1995) and although these have tended to lead to some improvements in individuals’ performance, these gains are modest and are rarely sustained in the long-term (Jarrold, Baddeley, & Phillips, 1999). This suggests that rehearsal deficits might not lie at the heart of individuals’ difficulties in verbal short-term memory.

Support for this suggestion comes from studies that have examined the rate at which individuals with Down syndrome might be expected to rehearse material in verbal short-term memory. According to Baddeley’s model, the efficiency of rehearsal is constrained by its speed – individuals who are able to rehearse more rapidly are able to maintain more memory items in the phonological store (Baddeley, Thomson, & Buchanan, 1975; Standing & Curtiss, 1989). Furthermore, material which takes longer to rehearse is harder to maintain for the same reason, providing a potential explanation for word length effects in immediate serial recall (Baddeley et al., 1975; Standing, Bond, Smith, & Isley, 1980). Consequently, if Down syndrome is associated with atypically slow rehearsal then this could account for individuals’ poor verbal short-term memory performance.
This possibility has been evaluated by examining individuals’ overt speech rates, based on the assumption that rate of covert subvocal rehearsal equates to rate of overt repetition (Baddeley, et al., 1975). Hulme and Mackenzie (1992) found that individuals with Down syndrome had reliably slower mean articulation rates than typically developing controls, however more recent studies have failed to replicate this difference. In our work we have found no reliable slowing in the average speech rates of individuals with Down syndrome relative to either children with moderate learning difficulties (Jarrold et al., 2000) or typically developing individuals (Jarrold, Cowan, Hewes, & Riby, 2004). Similar results have also been reported by Kanno and Ikeda (2002) and by Seung and Chapman (2000). Having said this, a more detailed analysis does suggest some speech production difficulties in Down syndrome, which might account for Hulme and Mackenzie’s findings. Seung and Chapman (2000) found that, while individuals with Down syndrome produced their response to a digit span task at the same rate as controls once they had begun responding, they took reliably longer to initiate their responses (see also Bunn, Simon, Welsh, Watson, & Elliott, 2002). Similarly, Jarrold et al. (2004) showed that, although individuals with Down syndrome actually articulated words more rapidly than typically developing controls, they left longer gaps between words of a long spoken duration. Both of these results are suggestive of speech planning difficulties in Down syndrome (see above). The extent to which such a difficulty is likely to impact on subvocal rehearsal depends on whether these difficulties are due to planning problems at the internal or articulatory level (Waters, Rochon, & Caplan, 1992). At present this is difficult to determine, although the fact that individuals with Down syndrome make more speech errors when repeating words from memory than when reading them (Bunn et al., 2002) suggests planning problems that may go beyond the articulatory level.

Whatever the case, the view that poor verbal short-term memory performance is the result of slowed rehearsal is called into serious question by the additional fact that speech
Short-term memory rates do not correlate with memory span in Down syndrome. In contrast to data from typically developing adults (see above), and indeed some other developmental conditions (Avons & Hanna, 1995; Jarrold et al., 2004; Raine, Hulme, Chadderton, & Bailey, 1991), studies have consistently failed to find a relationship between verbal short-term memory performance and rate of articulation of to-be-remembered items in Down syndrome (Comblain, 1996; Hulme & Mackenzie, 1992; Jarrold et al., 2004; Seung & Chapman, 2000; Vicari, Marotta, & Carlesimo, 2004). This finding suggests that rather than suffering from slowed rehearsal, individuals with Down syndrome might not typically engage in rehearsal at all.

At first sight, this view appears to be challenged by data from studies that have examined the magnitude of word length effects shown in short-term recall by individuals with Down syndrome. Although Hulme and Mackenzie (1992) failed to find reliable word length effects among their sample of individuals with Down syndrome, subsequent studies have shown clear word length effects in immediate serial recall paradigms (Broadly, MacDonald, & Buckley, 1995; Comblain, 1996; Jarrold et al., 2000; Kanno & Ikeda, 2002; Laws et al., 1995; Vicari et al., 2004). This difference in results might reflect the relatively poor baseline performance of individuals with Down syndrome, which in turn makes it relatively difficult to observe decrements in performance in ‘harder’ conditions.

Nevertheless, the fact that reliable word length effects are observed in serial recall in Down syndrome might appear to suggest that rehearsal is taking place, given the suggestion that the word length effect arises because of differences in rehearsal time required for words of different spoken duration (Baddeley et al., 1975).

However, an alternative explanation of the word length effect is that differences in spoken duration lead to differences in the time taken to produce output responses to verbal immediate serial recall tasks (Cowan et al., 1992); the argument being that the greater time
taken to produce long as opposed to short words leads to greater forgetting of still to be recalled list items held in memory (though see Lovatt, Avons, & Masterson, 2002). Indeed, both ‘internal’ rehearsal effects and ‘external’ output effects might contribute to the typical word length effect observed in serial recall paradigms with adults (Avons, Wright, & Pamme, 1994; Baddeley, Chincotta, Stafford, & Turk, 2002). Consequently, one might still expect to see a word length effect in standard serial recall, albeit perhaps a diminished one, among individuals who are not rehearsing. Given this, studies have increasingly employed paradigms such as probed recall, which remove the need for a spoken serial response, in order to test for the presence of word length effects that can be more confidently attributed to internal rehearsal processes. The one study that, to our knowledge, has explored these effects using probed recall among individuals with Down syndrome (Jarrold et al., 2000) found a reliably smaller word length effect under probed recall than serial recall conditions, and showed that the size of this effect was not significantly different from zero in the former case. In other words, although individuals with Down syndrome do tend to show word length effects in traditional recall paradigms, they do not show this effect in a task that removes serial output demands, suggesting that they are not engaging in rehearsal.¹

One might therefore be inclined to argue that poor verbal short-term memory performance in Down syndrome reflects a rehearsal failure in Down syndrome, such that individuals show impoverished verbal recall relative to their rehearsing peers (cf. Hulme & Mackenzie, 1992). The problem with this suggestion is that there is considerable evidence that individuals with Down syndrome show poorer verbal short-term memory performance than comparison groups who also appear not to be rehearsing. Since Flavell, Beach, and Chinsky (1966) showed that children younger than seven tend not to make lip movements when maintaining lists of verbal items, many have suggested that children younger than seven do not engage in spontaneous verbal rehearsal (e.g., Gathercole & Adams, 1993).
Potential support for this view comes from the evidence reviewed above which suggests that children younger than 7 do not spontaneously recode visually presented verbal information into a phonological code – a process thought to be mediated by the same subvocal ‘re-naming’ of items than occurs in rehearsal. In addition, Henry (1991) failed to find a reliable word length effect in verbal probed recall among 5-year-old typically developing children (see also Allick & Siegel, 1976; Balthazar, 2003), suggesting that word length effects observed in children of this age with serial recall of auditorily presented information may reflect output rather than rehearsal effects (see above, though see also footnote 1). Finally, although reliable correlations are typically observed between individuals’ speech rates and their immediate verbal serial recall among adults (e.g., Cowan et al., 1998; Standing et al., 1980; Tehan & Lalor, 2000), the correlations between these measures are often considerably weaker among children aged less than seven years (Ferguson, Bowey, & Tilley, 2002; Gathercole & Adams, 1993; Gathercole, Adams, & Hitch, 1994; Jarrold et al., 2004).²

Consequently when individuals with Down syndrome are compared to typical developing comparison individuals who are aged less than seven years, or individuals with learning difficulties functioning below the seven-year mental age equivalent level, one would not necessarily expect any individuals to be engaging in spontaneous rehearsal. Indeed, Balthazar (2003) found no reliable word length effects in the probed recall of individuals with language impairment who, though aged seven were functioning below this level in mental age terms. More directly, and as noted above, Jarrold et al. (2000) reported similar results among their individuals with Down syndrome who had a mean vocabulary mental age of below five years, but also found no reliable word length effect under probed recall conditions among both typically developing and learning disabled controls of an equivalent vocabulary level. In addition, neither these individuals with Down syndrome nor learning disabled (Jarrold et al., 2000) or typically developing (Jarrold et al., 2004) individuals
showed reliable correlations between their speech rates and span performance. In other words, although individuals with Down syndrome showed impaired overall verbal short-term memory performance in these two studies, it appears that this deficit cannot be explained in terms of a selective failure in rehearsal among this group.

If this is the case, and if one still wishes to interpret the poor verbal short-term memory performance of individuals with Down syndrome in terms of Baddeley’s phonological loop framework, then one is forced to argue that individuals must suffer from some form of impairment to the phonological store component of this model. In fact, this might take one of two forms (cf. Gathercole & Baddeley, 1990a); individuals with Down syndrome might suffer from atypically rapid loss of information from the store, or forgetting might occur at a normal rate but from a store of relatively reduced capacity. At first sight these two possibilities might appear to be conceptually equivalent – more rapid forgetting would appear to lead to a functional reduction in capacity – but we believe they can be distinguished from each other.

For example, in our recent work (Purser & Jarrold, in press) we have explored whether slowing the rate of presentation of verbal information in a short-term memory paradigm has a particularly detrimental effect on the performance of individuals with Down syndrome. Among adults, slowing presentation rates typically does not reduce verbal serial recall performance (Baddeley, Lewis, & Vallar, 1984), but this may well be because individuals are rehearsing and can therefore offset any extra degree of forgetting with the greater opportunities for rehearsal afforded by a more spaced presentation (Baddeley & Lewis, 1984; Brown & Hulme, 1995). However, if individuals are not rehearsing, then one might well expect the longer maintenance intervals associated with slower presentation rates to lead to poorer recall (cf. Vallar, Di Betta, & Silveri, 1997). Indeed, in two studies in which we examined probed recall of words from four-item lists under either faster or slower
Short-term memory presentation rates, both individuals with Down syndrome and typically developing controls showed poorer recall when presentation was slower. However, the key finding was the fact that, in both experiments, individuals with Down syndrome were no more affected by this rate manipulation than were controls. In other words, although forgetting from verbal short-term memory was occurring, there was no evidence that this loss of information was any more rapid for individuals with Down syndrome.

This leaves the possibility that individuals with Down syndrome suffer from reduced phonological store capacity. One way in which this has been investigated is by examining the magnitude of the phonological similarity effect shown in verbal short-term memory paradigms by individuals with Down syndrome. The standard phonological similarity effect is the finding that individuals show poorer short-term recall of information that is phonologically confusable than material which is phonologically distinct (Baddeley, 1966; Conrad & Hull, 1964), a result which implies that verbal material is held in short-term memory in a phonological code. Following this, some authors have further suggested that the magnitude of this effect might provide an index of the capacity of the phonological store, with a smaller similarity effect indicating reduced phonological store capacity (Vallar & Papagno, 1995; Vicari et al., 2004), although one might equally argue that phonologically similar materials might become more confusable as phonological storage capacity reduces.

Indeed, the evidence concerning the size of the phonological similarity effect in Down syndrome is mixed. Varnhagen, Das and Varnhagen (1987) found no reliable effect among their sample of individuals with Down syndrome, but presented individuals with 4 item lists of either phonologically similar or dissimilar words despite the fact that individuals’ average word spans was only 2 items. Consequently, it is possible that the use of supra-span lists may have discouraged individuals from attempting to hold all items in verbal short-term memory (see Jarrold, Baddeley, & Phillips, 1999). Indeed, both Broadley et al. (1995) and Comblain
(1996) found a reliable phonological similarity effect among their samples with Down syndrome. Other studies that have compared the magnitude of this effect among individuals with Down syndrome and controls have produced similarly mixed findings. Jarrold et al. (2000) found comparable phonological similarity effects among individuals with Down syndrome and individuals with moderate learning difficulties in probed recall. However, both Hulme and Mackenzie (1992) and Vicari et al. (2004) found a reliably smaller phonological similarity effect among individuals with Down syndrome than among controls. Once again though, this latter finding might reflect methodological constraints; Vicari et al. (2004) report that floor effects operated to limit the variability of individuals’ recall of words in their phonologically similar condition. Furthermore, although there may be intra-individual variation in the magnitude of the phonological similarity effect among typically developing adults (Logie, Della Sala, Laiacoma, Chambers, & Wynn, 1996), neuropsychological patients with clear verbal short-term memory deficits often show a standard sized effect (Vallar & Papagno, 1995). Consequently, although the absence of a phonological similarity effect would appear to be strong evidence for a complete absence of phonological coding in verbal short-term memory provided that floor effects are avoided (Vallar et al., 1997), it may well be that a typically sized effect is observed provided that at least some material is held in the phonological store, regardless of the store’s capacity. Consequently, these data fail to provide clear support either for or against the suggestion of a reduced phonological store capacity in Down syndrome.

More direct evidence for a capacity limitation comes from studies that have examined serial position effects in the verbal short-term memory performance of individuals with Down syndrome. In fact, such studies are limited in number, presumably because the relatively poor performance of individuals on immediate verbal serial recall tasks limits the scope for serial position analyses. However, the use of probed recall tasks can potentially
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extend the range of serial positions over which individuals produce meaningful verbal short-term memory data. In our probed recall study (Jarrold et al., 2000) we found that individuals with Down syndrome were only reliably impaired relative to controls on the first list position of three-item word lists. If one assumes that this does not reflect atypically rapid forgetting of information (see above) one reading of these data is that they reflect a reduced capacity for phonological storage of information in Down syndrome. Put somewhat simplistically, if individuals with Down syndrome were unable to maintain all three items in short-term memory to the same extent as controls, but rather were able to successfully maintain two items, then one would expect them to engage in a successive updating of information as the to-be-remembered list was presented. Consequently the final two items, but not the first, would be maintained in verbal short-term memory at the end of the presentation, leading to unimpaired performance when either of these positions was probed. Support for this reading of the data comes from a more recent experiment reported by Purser and Jarrold (in press, Experiment 2). In this instance, individuals’ memory for item information was probed by presenting four item lists followed by the immediate and rapid re-presentation of three of these items. The participants’ task was to recall the remaining item in the presented list that had not been re-presented. The serial position of this probed item within the presentation list was systematically varied across trials, and the results showed that individuals with Down syndrome were unimpaired when the final position in the four-item list was probed, but performed poorly at all other positions. Once again this suggests a reduced verbal short-term capacity among these individuals, such that only the most recently presented item or items are successfully maintained.

CONSEQUENCES OF A VERBAL SHORT-TERM MEMORY DEFICIT

The research reviewed above confirms that individuals with Down syndrome do perform poorly on tests of verbal short-term memory, and that this poor performance cannot
wholly be explained in terms of hearing difficulties, problems in speech production, or reduced linguistic knowledge. There is, therefore, clear support for the view that Down syndrome is associated with a fundamental verbal short-term memory deficit. Furthermore, this deficit appears not to be related to problems of rehearsal, but more likely reflects problems of phonological storage, and potentially, a reduced capacity for the short-term storage of phonological information. In this final section, we consider the broader consequences of this verbal short-term memory deficit for certain aspects of language development in Down syndrome.

Baddeley, Gathercole and colleagues (e.g., Baddeley, Gathercole, & Papagno, 1998) have argued that the phonological store component of Baddeley’s model plays an important role in the language acquisition process, particularly during children’s new word learning. Their suggestion is that verbal short-term memory is required in order to successfully maintain and represent the phonological form of new word sounds when they are first encountered, and to support subsequent learning. This view is supported by evidence from a number of sources. Verbal short-term memory performance is clearly related to children’s level of receptive vocabulary, even when potentially confounding measures such as level of non-verbal ability are controlled for (see Baddeley et al., 1998). Indeed, longitudinal and quasi-longitudinal designs have shown that, among young children, early measures of verbal short-term memory performance do predict subsequent levels of vocabulary attainment (Gathercole, Willis, Emslie, & Baddeley, 1992; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). More directly, participants’ verbal short-term performance is also correlated with their ability to learn novel phonological forms in experimental word learning paradigms (Baddeley, 1993; Baddeley, Papagno, & Vallar, 1988; Gathercole & Baddeley, 1990b; Gathercole, Hitch, Service, & Martin, 1997; Papagno & Vallar, 1995).
The clear prediction that follows from this research is that poor verbal short-term memory in Down syndrome should lead to difficulties in vocabulary acquisition. It is certainly the case that vocabulary is delayed in Down syndrome relative to age, or perhaps even non-verbal mental age levels (Chapman, 1995; 1997), and this delay does not appear to be caused by difficulties in the ‘conceptual’ demands of acquiring word meanings. For example, Chapman, Kay-Raining Bird, and Schwartz (1990) reported relatively strong ‘fast mapping’ skills in Down syndrome – that is, when faced with a novel word, individuals readily assumed that this must refer to a novel, rather than familiar, object. Nevertheless, vocabulary is certainly not the weakest aspect of the language skills of individuals with Down syndrome, and is often markedly stronger than individuals’ syntactic skills (Chapman, 1995; Fowler, 1990; Laws & Bishop, 2004; Vicari, Caselli, Gagliardi, Tonucci, & Volterra, 2002). Although it has been suggested that verbal short-term memory impairments might lead on to grammatical difficulties in addition to problems in new word learning (Adams & Gathercole, 1995; Baddeley et al., 1998), the evidence and theoretical rationale for a causal relationship with syntactic development is less strong than it is for vocabulary (see Baddeley et al., 1998). Consequently, the fact that vocabulary is not particularly impaired within the domain of language functioning in Down syndrome is problematic for the view that poor verbal short-term memory leads to poor vocabulary learning.

One possibility is that individuals with Down syndrome are able to compensate for their poor verbal short-term memory and acquire vocabulary primarily through an alternative route. Baddeley (1993) reported the case of an individual (without Down syndrome) who acquired normal vocabulary despite a severe developmental short-term memory deficit and despite poor performance on an experimental non-word learning paradigm. As a result Baddeley suggested that it is “unlikely that phonological short-term memory sets the limit for adult vocabulary, which seems much more likely to be determined by a combination of
richness of linguistic environment, coupled with the intelligence to deduce the meaning of unfamiliar words in context” (p. 144). It is possible that individuals with Down syndrome rely more than is typical on contextual information to support their vocabulary acquisition and (perhaps more pertinently) to aid their performance on vocabulary tests.

If individuals with Down syndrome are not relying on verbal short-term memory during vocabulary acquisition, then one might expect that vocabulary knowledge would not be correlated with measures of verbal short-term memory to the extent that it is in typically developing children. Laws (1998) found that receptive vocabulary was reliably related to nonword repetition performance in a sample of 33 individuals with Down syndrome even when age and nonverbal ability was controlled. However, she failed to find a significant corresponding relationship between vocabulary and digit span in this group. Nevertheless, a five-year follow-up (Laws & Gunn, 2004) of 31 of these individuals showed that both time 1 nonword repetition and time 1 digit span scores predicted time 2 vocabulary knowledge even when time 1 vocabulary and chronological age were controlled for (cf. Gathercole et al., 1992). As Laws and Gunn note, these findings are currently the strongest evidence for the presence of the typical relationship between verbal short-term memory and new word learning in Down syndrome.

An important caveat, however, comes from the consideration of developmental changes in the relationship between vocabulary knowledge and verbal short-term memory. Jarrold et al. (2004) proposed that, although verbal short-term memory capacity plays a critical role in early vocabulary acquisition, as the level of vocabulary knowledge increases, the association between vocabulary knowledge and verbal short-term memory is increasingly driven by the top-down influence of vocabulary knowledge on verbal short-term memory performance. Consequently, significant associations between vocabulary and verbal short-term memory reported in Down syndrome are not necessarily indicative of a role of verbal short-term
memory in vocabulary acquisition. Indeed, Cairns and Jarrold (in press) reported that a reliable correlation between vocabulary knowledge and nonword repetition in individuals with Down syndrome was not reduced by partialling out individuals’ digit spans, suggesting that it was not mediated by verbal short-term memory.

An important unresolved issue, therefore, is whether individuals with Down syndrome rely on an alternative mechanism for acquiring vocabulary or whether measures of vocabulary knowledge used in existing studies are simply insensitive to their difficulties. This question could in principle be addressed by looking at performance on experimental word-learning tasks and on measures of vocabulary knowledge that are sensitive to the strength and accuracy of phonological representations (as opposed to semantic knowledge). Given the aforementioned changes in the relationship between vocabulary knowledge and verbal short-term memory in typical development, it will be important to compare individuals with Down syndrome and those with other forms of learning disability who are of a comparable chronological age and developmental level.

CONCLUSIONS

The above review has shown that individuals with Down syndrome perform particularly poorly on tests of verbal short-term memory. Furthermore, although it is clear that the hearing difficulties, speech production problems, and relatively impoverished linguistic knowledge that are often associated with the condition are likely to affect performance on standard verbal short-term memory tasks such as digit span, there is good evidence to indicate that Down syndrome is associated with a fundamental verbal short-term memory deficit. What is somewhat less clear is how one should conceptualise this deficit in terms of Baddeley’s phonological loop model – although there is evidence for a reduction in the capacity of phonological storage – and whether these deficits equally affect performance
on more complex working memory tasks as one would expect. These are clearly issues for further research.

However, arguably the most pressing current research issue concerns the possible consequences of a verbal short-term memory deficit in Down syndrome for aspects of individuals’ language development. There are clear theoretical and empirical reasons to expect a detrimental impact of such a deficit on language acquisition, and on vocabulary development in particular, but at present there is little firm evidence for these effects in Down syndrome. In the absence of this evidence, the study of verbal short-term memory performance in Down syndrome currently tells us more about the structure of short-term memory in general than it does about the development of individuals with Down syndrome. However, if future research can more clearly specify the consequences of poor verbal short-term memory for other aspects of cognitive development then this would clearly have important implications for the type of educational and remedial interventions that might usefully be applied among individuals with the condition.
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Footnotes

1 One concern about the comparison of effect sizes in serial and probed recall is that probed recall is likely to be a less sensitive procedure, and therefore may be a less powerful test of a phenomenon such as the word length effect. This reduction in sensitivity follows from the fact that, across trials, probed recall tasks typically probe for recall of items at each serial position in the list. Because probes are provided immediately after test, performance for later serial positions tends to be at or near ceiling (e.g., Waugh & Norman, 1965), reducing the power to find condition effects, particularly when short list lengths are presented.

2 A problem with the view that individuals begin rehearsing at around a developmental level of seven years is that there is no evidence of a qualitative jump in performance levels around this age among typically developing individuals. Indeed, age-based changes in immediate verbal serial recall across childhood appear quantitative and continuous rather than discrete (e.g., Case et al., 1982; Gathercole, Pickering, Ambridge, & Wearing, 2004; Hulme, Thomson, Muir, & Lawrence, 1984; Nicolson, 1981).

3 Vicari et al. (2004) do report serial position data for free recall of 12 item lists by individuals with and without Down syndrome, and showed comparable recency effects among these groups at positions 10, 11 and 12. However, it is questionable whether the recency portion of the free recall curve reflects the contribution of short-term memory processes as was once thought to be the case (see Baddeley & Hitch, 1977).

4 It is also possible that the failure to find reliable correlations between digit spans and receptive vocabulary in these samples reflects the relatively attenuated range of digit span scores that one tends to observe among individuals with Down syndrome.