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Individual differences in processing speed mediate a relationship between working memory and children's classroom behaviour☆

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ABSTRACT

Previous studies have shown an association between children's working memory performance and teacher ratings of classroom inattention, leading to the suggestion that children who appear inattentive may in fact suffer from reduced working memory capacity. However, working memory performance is determined by a range of factors and in this study we examine the relationships between the teacher ratings of classroom behaviour and the various constraints on working memory performance in a representative sample of 6- to 8-year-olds in mainstream education. Analysis of individual differences confirmed that working memory scores could be decomposed into the following components: storage capacity, processing efficiency, and the residual variance that results from combining storage and processing operations. However, only processing efficiency was reliably related to teacher ratings of individuals' ability to concentrate and learn in the classroom, suggesting that individual differences in basic speed of processing, rather than in memory capacity, drive this relationship.

1. Introduction

Working memory is the ability to hold in mind information in the face of distraction in order to engage in goal-directed behaviour (Kane, Bleckley, Conway, & Engle, 2001). Current theoretical models therefore emphasise the need for individuals to employ some form of executive control (Baddeley, 1986) or controlled attention (Cowan et al., 2005; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2001) to keep representations active in working memory. Indeed, Engle et al. (1999) measured adults' working memory and short-term memory capacities, with the latter being defined in terms of participants' ability to remember items in correct serial order in the absence of any distraction. They found that working memory performance was related to short-term memory capacity, reflecting a common need for storage of to-be-remembered information. However, their working memory measures captured additional variance, that was also related to fluid intelligence, and which they ascribed to executive control abilities (see also Kane et al., 2004). Subsequent work has shown that working memory performance may in fact depend on at least three component abilities — short-term storage capacity, the ability to carry out the distracting 'processing' that is necessarily embedded in a working memory task, and the ability to combine these two demands (Bayliss, Jarrold, Gunn, & Baddeley, 2003). Taken together, these findings suggest that combining storage and processing operations in a working memory paradigm recruits additional, and potentially executive, resources over and beyond those involved in the storage and processing components themselves.

These theoretical analyses are consistent with evidence that measures of adults' working memory are stronger predictors of higher-level abilities such as reading, mathematics, and indices of intelligence than are measures of short-term memory (e.g., Oberauer, Schulze, Wilhelm, & Süß, 2005). Importantly, this greater predictive power of working memory measures has also been observed in children (e.g., Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Bayliss et al., 2003; Hitch, Towse, & Hutton, 2001). However, in addition to these relationships with measures of academic achievement, researchers and educational practitioners are increasingly suggesting that more general aspects of classroom behaviour might depend on working memory capacity. For example, Gathercole, Lamont, and Alloway (2006) studied the classroom behaviour of three boys who had previously been identified as having poor working memory. They found that these individuals had difficulty in following complex instructions, arguably because of the need to simultaneously hold in mind information from the start of a complex sentence while processing the remainder of it (see also Gathercole, Durling, Evans, Jeffcock, & Stone, 2008). They suggested that apparent problems of inattention in such individuals might be better understood as working memory difficulties; individuals who struggle to hold in mind classroom instructions in the face of other distractions are likely to forget what has been asked of them, fail to stay 'on-task', and appear distractible.

In a series of subsequent studies, Gathercole and colleagues (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Gathercole, Alloway, et al., 2008; Gathercole, Durling, et al., 2008) examined teacher ratings of classroom

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behaviour in samples of children who had previously been identified as showing particularly poor working memory performance using the Conners' Teaching Rating Scale — Revised, Short Form (Conners, 2001). In each study individuals with poor working memory function were particularly impaired on the cognitive problems/inattention subscale of this version of the Conners' form, relative to comparison groups without working memory difficulties, supporting the view that poor working memory performance is associated with apparent attentional problems in a classroom setting. This work is of considerable importance because it suggests that professionals risk incorrectly ascribing fundamental problems of attention to children that are instead largely mediated by working memory difficulties (see also Lui & Tannock, 2007; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

However, while undoubtedly plausible there are two reasons why this suggestion may be premature at this stage. First, the individuals with low working memory performance assessed in these studies also tended to have low IQ, raising the possibility that rated problems of inattention in these groups were driven by a more general factor rather than by working memory difficulties specifically. Second, as outlined at the outset, working memory performance is multiply determined. Consequently, impaired working memory performance might reflect diminished executive control abilities, but it might equally result from impaired short-term memory performance, or a reduction in the efficiency with which the processing component of a working memory task is performed.

One aim of the current work, therefore, was to attempt to replicate the finding of an association between working memory task performance and teacher ratings of classroom behaviour in a sample where individuals would be expected to be performing in the typical IQ range (cf. Lui & Tannock, 2007). The second aim was to better understand the nature of any relationship that might be observed between working memory performance and teacher ratings of behaviour. Specifically, in addition to measuring working memory using standard 'complex span' measures of working memory that combine processing and storage demands (Conway et al., 2005) we also took independent measures of the storage and the processing components of these complex span tasks (cf. Bayliss et al., 2003) in order to isolate the key factor underpinning any relation between working memory performance and teacher ratings of classroom behaviour.

The current study did not manipulate the type of processing involved in our complex span tasks because previous work had indicated that individual differences in processing speed were domain-general (Bayliss et al., 2003). Rather, two complex span tasks were employed that both involved verbal processing, with one requiring verbal storage and the other requiring visuo-spatial storage. In addition to measuring performance on these two complex span tasks, participants' verbal and visuo-spatial short-term memory performance was assessed using 'simple span' tasks that exactly matched the storage requirements of the complex span tasks but without any concurrent processing. Similarly, individuals' processing speed was measured using the same processing task as employed in the complex span tasks, but in the absence of any storage load. Finally, teachers rated classroom behaviour using a recent version of the Conners' scale. As a result, this collection of measures allowed us to examine the relationship between working memory and ratings of classroom behaviour, and then to break down this relationship in terms of the component processes that constrain an individual's working memory performance.

2. Method

2.1. Participants

Participants were 47 children, who represented all individuals from four school classes for whom parental consent was obtained. Two of these classes were for children in UK Year 2 (US Grade 1), and were situated in an infant school, the other two classes were for children in UK Year 3 (US Grade 2) and were in the linked junior school on the same, shared geographical site. These schools were chosen because they showed close to national average levels of attainment on 'Key Stage 2' assessments of reading and mathematics for children aged 11 years. In addition, the percentage of children in the infant and junior school recorded as eligible for receiving free school meals in the last available national census (January 2010) was 3.9 and 15.7 respectively (national average for this age range = 18.5%). Twenty-one children (10 boys) were in Year 2 and 26 (17 boys) were in Year 3. The age of the sample ranged between 6 years 10 months and 8 years 3 months, with a mean age of 7 years 6 months (SD = 4 months).

2.2. Procedure

Participants were tested two different complex span tasks (verbal and visuo-spatial), two different simple span tasks (digit and Corsi), and a measure of processing speed that was conducted twice. These tasks were presented in two sessions, each of around 30 min in length. In the first session individuals received processing speed assessment 1, verbal complex span, and Corsi span, in that order. In the second session they were given the visuo-spatial complex span, digit span, and processing speed assessment 2, in that order. In addition, each participant's classroom behaviour was rated by a teacher who had taught that individual for the past 3 months or more, using the Conners' 3 Teachers' Short Form (Conners, 2008).

2.2.1. Complex span tasks

The two complex span tasks required concurrent storage and processing, and were formed by crossing two types of storage (verbal or visuo-spatial) with a verbal processing component. On any trial participants were presented with a series of storage items, with a 3 s processing window following the presentation of each storage item. The processing task involved making a phonological discrimination on a series of nonwords that were presented during the processing window. Specifically, participants had to press one key if the nonword began with a 'k' sound and another key if it did not. Nonwords were selected from a pre-recorded set of 84 one-syllable nonwords that were recorded in a female voice, and which lasted 500 ms each. Half of the nonwords began with a 'k' sound. When a participant made a key press response to a nonword presented in any given processing window, a further nonword was presented following a gap of 250 ms. In this way, sufficient nonwords were presented within a given processing window to fill its 3 s length. At this point the next storage item was presented, or, if the end of the trial had been reached, recall was signalled by the onset of a recall screen.

In the verbal complex span task, storage items were numbers drawn from the set 1 to 9, which were visually presented individually in the centre of the screen for 1 s in 120 point Arial font. In the visuo-spatial complex span task, storage items were selected from a 3 × 3 matrix of 9 squares (each approximately 2.5 cm × 2.5 cm). This matrix was displayed on the screen for 1 s during each storage item presentation phase, with one of the squares highlighted in red. Recall from a trial in the verbal complex span task involved the participant saying the list of numbers that had been presented, with instructions that recall should be in correct serial order. Participants recalled the items from trials in the visuo-spatial complex span task by touching on the appropriate squares of a blank matrix shown on the computer screen, again under serial order recall instructions.

Each task began with 4 trials at list length 2. If the participant correctly recalled all of the storage items in correct serial order on at least one of these trials, they then moved on to 4 trials at list length 3, if not, the task ended at that point. The same progression rule was operated up to a list length of 6, giving a total possible maximum of 20 trials. Performance was coded using a partial credit score (see Conway et al., 2005) in which the proportion of items on each trial recalled in correct serial position was totalled across all trials (maximum score of 20).