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Developmental changes in the engagement of episodic retrieval processes and their relationship with working memory during the period of middle childhood

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We examined the development of children's engagement of the episodic retrieval processes of recollection and familiarity and their relationship with working memory (WM). Ninety-six children (24 in four groups aged 8, 9, 10, and 11 years) and 24 adults performed an episodic memory (EM) task involving old/new, remember/know (R/K), and source memory judgements and numerous WM tasks that assessed verbal and spatial components of WM and delayed short-term memory (STM). Developmental changes were observed in EM with younger children (8-, 9-, 10-year-olds) making fewer remember responses than 11-year-olds and adults while 11-year-olds did not differ from adults. Only children aged 10 years plus showed a relationship between EM and WM. EM was related to verbal executive WM in 10- and 11-year-old children suggesting that children at this stage use verbal strategies to aid EM. In contrast, EM was related to spatial executive WM in adults. The engagement of episodic retrieval processes appears to be selectively related to executive components of verbal and spatial WM, the pattern of which differs in children and adults.

Research investigating developmental changes in the engagement of the episodic retrieval processes of recollection and familiarity is relatively limited. Studies conducted to date have reported distinct developmental trajectories for the development of recollection and familiarity in children. Developmental changes have been reported in the engagement of recollection across middle childhood and into adolescence (Billingsley, Smith, & McAndrews, 2002; Brainerd, Holliday, & Reyna, 2004; Defeyter, Russo, & McPartlin, 2009; Ghetti & Angelini, 2008; Holliday, 2003). The specific age at which children engage recollection to the same degree as adults is however as yet unknown. The nature of the relationship between episodic retrieval processes and working memory (WM) is also limited. Recent research within the adult literature

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has reported interactions between the two; early-stage maintenance in WM has been reported to predict subsequent long-term memory retrieval (Ranganath, Cohen, & Brozinsky, 2005). The current study set out to investigate developmental changes in the engagement of episodic retrieval processes at specific ages within the period of middle childhood and to examine the relationship between episodic memory (EM) and a range of aspects of WM.

Developmental changes in episodic retrieval processes

While children's accuracy in their memories for previous events has been the focus of considerable investigation within the psychological literature, most research has tended to focus on the quantitative rather than the qualitative aspects of memory performance, which are in fact thought to be more important in everyday life situations (Roderer & Roebers, 2009). Knowledge of developmental changes in the engagement of the specific episodic retrieval processes of familiarity and recollection is relatively limited, which is surprising given the wealth of research that has investigated the engagement of episodic retrieval processes in adults (Rhodes & Donaldson, 2007, 2008; Yonelinas, 2002). Popular dual process theories of EM (e.g., Atkinson & Joula, 1973; Jacoby 1991; Mandler, 1980; Tulving, 1985) explain familiarity and recollection as two distinct processes. Familiarity is a relatively automatic process involving recognition without the retrieval of contextual information, such as the common experience of meeting someone on the street and feeling that you know them without being able to recollect any specific details about them. Recollection, in contrast, is a more controlled process that supports retrieval of information and its context (Yonelinas, 2002). Research conducted with children has suggested developmental changes in the use of recollection and familiarity to support retrieval during childhood.

A number of studies have reported distinct developmental trajectories for recollection and familiarity (e.g., Brainerd *et al.*, 2004; Ghetti & Angelini, 2008). Employing the conjoint-recognition procedure (CRP), Brainerd *et al.* (2004) reported that use of recollection to support retrieval was 2–3 times higher in 14-year-olds than 7-year-olds whereas familiarity was stable across this period. Ghetti and Angelini (2008) used the receiver operating characteristics curves (ROC) method to calculate the engagement of recollection and familiarity and reported a similar pattern of engagement of episodic retrieval processes from 6 to 18 years old. Children aged 8, 10, 14, and 18 did not differ in engagement of familiarity while developmental changes were observed in recollection. While 6- and 8-year-olds did not differ, use of recollection was lower in both age groups in contrast to 10- and 18-year-olds and 6-year-olds additionally differed from 14-year-olds.

Another approach to measure episodic retrieval processes has been the comparison of item and source memory judgements. Cycowicz, Friedman, Snodgrass, and Duff (2001) compared item and source recognition memory performance for children aged 7–8 years and college students. Performance differences between children and adults on an item recognition task that encouraged the use of familiarity was observed but was less pronounced than recollection differences (Cycowicz *et al.*, 2001). In a further study, the authors compared item and source memory in children aged 9–10 and 12–13 while event-related potentials (ERPs) were recorded (Cycowicz, Friedman, & Duff, 2003). While the ERP effect commonly associated with recollection (known as a parietal old/new effect) was elicited in both item and source memory tasks for both groups of children, suggesting that recollection was used as a basis of memory judgements for all age groups, the topography of the effect differed according to age group during performance of the source memory task alone. This finding suggests that children and adults rely on different neuronal networks in the retrieval of source information.

As has been noted in recently published work (Ghetti & Angeleini, 2008; Roderer & Roebers, 2009), the qualitative or subjective aspect of children's memory has been relatively ignored in the literature. Billingsley *et al.* (2002) incorporated qualitative measures of episodic retrieval and the findings reported for developmental changes in recollection generally converge with those assessed using quantitative methods. Billingsley *et al.* (2002) employed a remember/know (R/K) task (Tulving, 1985; see Yonelinas, 2002) that provides an index of familiarity ('Know' responses) and recollection with familiarity ('Remember' responses) and reported that 8- to 10-year-old children had a lower proportion of remember responses than adolescent participant groups aged 14–16 and 17–19 years. Findings relating to the engagement of familiarity within the Billingsley study show slight differences from other studies. In contrast to Ghetti and Angelini (2008) and Brainerd *et al.* (2004) who reported no further changes in familiarity beyond the age of 8, Billingsley *et al.* (2002) reported that 8- to 10-year-olds had a higher proportion of correct know responses than the adolescent groups. Know responses were at floor for all groups, however, making it difficult to make definitive conclusions regarding familiarity differences between age groups. The study may have also been underpowered to detect significant effects across all age groups, as each group comprised just 13 children. For example, it is difficult to ascertain whether a lack of significant differences reported in the proportion of remember and know responses between 8- and 10-year-olds and 11- and 13-year-olds reflects power issues or a lack of developmental changes during these time points. The pattern of data reported graphically (see Billingsley *et al.*, 2002) indeed suggests that a lack of power may underlie the non-significant changes between these age groups.

Thus, a growing body of research suggests distinct developmental trajectories for recollection and familiarity during childhood and there is consensus that developmental changes in the use of recollection continue across the period of middle childhood and into adolescence. Importantly, these consistent findings have been reported across tasks with very different parameters with both quantitative and qualitative indices of episodic retrieval processes (R/K, ROC, CRP, ERP). Collectively, these studies suggest that children continue to show developmental changes in the use of recollection across the period of middle childhood and develop adult levels of engagement at some stage between the age of 8 years and early adolescence. The current study aimed to identify the specific age at which children show adult levels of recollection and to document possible corresponding developmental changes in the engagement of familiarity during middle childhood. It is predicted that the proportion of responses associated with recollection will increase across this period of middle childhood accompanied by a relative decrease in familiarity based responding. As research utilizing subjective measures of episodic retrieval is extremely limited an R/K task was used to assess the engagement of recollection and familiarity in children. This R/K task additionally incorporated a source memory judgement following remember responses to provide an objective record of children's memory for source information.

The relationship between episodic retrieval and working memory in children

It is well established that WM abilities undergo profound changes during the period of childhood up until the period of adolescence (Luciana & Nelson, 1998; Welsh, Pennington, & Grossier, 1991). While various models of WM have been proposed (e.g., Baddeley, 1986; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Shah & Miyake, 1996) the weight of evidence supports Baddeley's theoretical WM component model (Baddeley & Hitch, 1974; Baddeley, 1986, 2007). This model identifies verbal (phonological loop) and spatial (visuo-spatial sketchpad) WM components that are involved in the maintenance of information in short-term memory (STM) and a 'central executive' where stored information is controlled and manipulated. The relationship between the engagement of episodic retrieval processes and WM functioning is of particular interest because the ability to encode and retrieve from long-term memory ultimately depends on WM abilities used to encode information into long-term memory.

The link between WM and long-term memory is a current hot topic in memory research, arising from the revision of Baddeley's WM model to incorporate an episodic buffer, a system that is described as forming 'an interface between the three WM subsystems and long-term memory' (Baddeley, 2007, p. 13). Recent research within the adult literature has reported interactions between EM and WM. Ranganath *et al.* (2005) reported that early-stage maintenance in WM predicts subsequent long-term memory retrieval. Research investigating the relationship between EM and WM in children is limited. The current study aimed to investigate the relationship between a range of aspects of WM including verbal and spatial WM components assessing both storage and central executive aspects. As a number of studies have reported a link between executive functions and long-term memory in children (Drummey & Newcombe, 2002; Sluzenski, Newcombe, & Ottinger, 2004), it is predicted that central executive aspects of WM will in particular relate to episodic retrieval in children.

The present study

The present study had two principal aims. The first aim was to investigate developmental changes in children's engagement of familiarity and recollection at specific ages during the period of middle childhood. A second aim was to examine the relationship between the engagement of episodic retrieval processes and WM, which is known to develop during childhood. The study aimed to relate EM retrieval to verbal and spatial storage and central executive aspects of WM. The study further investigated the relationship between EM and delayed STM to examine the relationship between the ability to hold information in memory over time in STM and episodic retrieval from long-term memory. The developmental time points that were assessed covered a range of specific ages within the period of middle childhood (8–11 years). This period was chosen based on a lack of research examining changes in episodic retrieval processes at specific time points between the ages of 8 and pre-adolescence.

Method

Participants

One hundred and thirty-five participants were recruited to the study: 111 children and 24 adults. All children recruited to the study were screened with the Teacher rated Strengths and Difficulties Questionnaire (SDQ) [Goodman, 2001] to ensure that the child was not suffering from any mental or behavioural disorder that could affect memory performance, for example, the common developmental disorder Attention Deficit Hyperactivity Disorder (ADHD) (Rhodes, Coghill, & Matthews, 2005). A total of 96 children were rated as symptom free (T-score < 60) and were included in the

Table 1. Participant characteristics

Age (children: years; adults: mean, *SD*, range)	BPVS percentile rank *M* (*SD*)	Gender
8	64.6 (19.0)	12 M, 12 F
9	64.3 (18.2)	12 M, 12 F
10	60.0 (21.9)	13 M, 11 F
11	66.6 (22.8)	12 M, 12 F
Adults: 24, 5.0, 17–37	N/A	12 M, 12 F

study ($N = 24$ each group). The four child groups were matched on British Picture Vocabulary Scale (BPVS) percentile rank, an index of verbal ability ($F < 1, p > .05$) and gender (see Table 1). Parents of all participating children provided consent for their child to take part in the study in line with departmental ethics regulations that was secured for the study.

Materials and procedure

The BPVS (2nd Edition, Dunn, Dunn, Whetton, & Burley, 1997), an individually administered, norm-referenced, wide-range test of receptive vocabulary for Standard English was used to estimate general intellectual ability. The child groups were matched on BPVS percentile rank scores to ensure equivalent general intellectual ability (relative to age) across groups.

Episodic memory task

All participants performed a R/K task to assess the engagement of episodic retrieval processes. The task was created using the experimental program Eprime. In study phases of the experiment, participants were shown pictures presented on either the left or right hand side of the screen. The pictures comprised concrete objects based on common objects normed for children and adults (Snodgrass & Vanderwart, 1980). Each study image was preceded by a fixation cross that appeared on the screen for 2-s duration. Each study image was presented for 3-s duration and participants were instructed to try and remember each image and the location on the screen it was presented. In test phases, participants were presented either with studied (old items) or unstudied (new items) pictures presented at central fixation for 3-s duration. Participants were required to make a three-part response firstly indicating whether the item was old or new. If the item was judged to be old the participant was required to indicate whether they remember, knew, or merely guessed that the item was old. If the item was judged to be new, participants were presented with the next test image. The guess option was included because it was anticipated that young children would mistake 'Know' judgements for guessing. The inclusion of a guess response is thought to make know judgements less liberal and more accurate (Knott & Dewhurst, 2007). Finally, if the participants had chosen the remember option they were presented with a third set of responses and were required to indicate whether the stimulus was presented at the left or right hand side of the screen. A third option 'something else' was included in case the participant didn't remember the specific location but had a specific recollection about the image (e.g., one child commented that 'I remember seeing the snowman, because it was the first picture I saw in the Study Phase'). This task thus provided an index of familiarity ('Know' responses) and recollection with familiarity ('Remember' responses) in addition to a measure of memory for source. Each question remained on the screen until the participant responded. Participants completed a practice block comprising four pictures at study and eight (four old, four new) at test. The main part of the experiment comprised four study-test blocks. There were 16 pictures presented at each study phase and 32 (16 old, 16 new) presented at test phases.

Working memory tasks

Participants performed a range of WM tasks: verbal and spatial storage and executive WM tasks and a delayed STM task. Three of the tasks were taken from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Morris, Evendon, Sahakian, & Robbins, 1987): the Spatial Span (SSP), Spatial Working Memory (SWM), and Delayed Matching to Sample (DMtSs) tasks. These tasks have been extensively validated in both child and adult populations (Curtis, Lindeke, Georgieff, & Nelson, 2002; Luciana & Nelson, 1998; Rhodes, Coghill, & Matthews, 2004; Rhodes *et al.*, 2005, 2006; Robbins *et al.*, 1994) and typical developmental trajectories of performance have been reported (Curtis *et al.*, 2002; Luciana & Nelson, 1998; Robbins *et al.*, 1994). The components of verbal WM were assessed using WM tasks previously reported in the literature that have been designed to tap (a) verbal STM (maintenance of information, i.e., tapping the phonological loop) and (b) verbal executive WM (maintenance and manipulation of information, i.e., tapping the phonological loop + central executive). These tasks have been adapted by the lead author for use with children based on tasks used in a number of published studies (Cannon *et al.*, 2005; D'Esposito, Postle, Ballard, & Lease, 1999; Kim, Glahn, Nuechterlein, & Cannon, 2004). Specific task parameters are described below.

Short-term memory storage tasks

The storage components of WM were assessed using the verbal STM component task and the SSP task from the CANTAB battery. The verbal STM component task assesses the ability to maintain a string of three letters in memory (target), which is displayed on the screen for 2.5 s followed by a 6-s delay (in which a fixation cross is displayed). The participant is then required to decide whether the probe presented is a 'match' or 'non-match' to the target (Canon *et al.*, 2005; D'Esposito *et al.*, 1999; Kim *et al.*, 2004). The SSP task is a test of spatial STM capacity based on the Corsi block-tapping task (Milner, Corsi, & Leonard, 1991) that assesses a participant's ability to remember the spatial locations of a sequence of squares on a computer screen without placing demands on central executive functioning. The key measure on this task is the SSP Score. A participants' SSP is defined as the longest sequence that they could reproduce correctly within three attempts.

Executive working memory (WM) tasks

The central executive components of WM were assessed using the verbal executive WM component task and the SWM task from the CANTAB battery. The executive verbal WM task is similar in parameters to the verbal STM component task but in addition to assessment of maintenance of information this task also requires the participant to manipulate the information held in the WM (Baddeley, 1986). In the verbal executive task, participants had to put the letters displayed in alphabetical order in their minds and hold this manipulated version in their maintenance store during the delay. The target letters were displayed for 2.5 s and the delay that followed comprised a 6-s interval during which a fixation cross was displayed. The participant then had to decide whether the probe presented was a 'match' or 'non-match' of the manipulated version (Canon *et al.*, 2005; D'Esposito *et al.*, 1999; Kim *et al.*, 2004). The SWM task places similar places demands on central executive functioning. It is a self-ordered searching task (Petrides & Milner, 1982) task that assesses the participant's ability to retain spatial information and to simultaneously store and manipulate information in WM while working towards a goal. Participants are required to 'search through' a spatial array of coloured boxes presented on the screen to collect 'blue tokens' hidden inside the boxes. Returning to a box where a token has already been found constitutes a 'Between Search Error' (BSE). Participants must keep searching through all the boxes until they find the blue token at which point they proceed to find the next hidden blue token. Ultimately participants will find a blue token behind each of the boxes. Experimental trials commence with a four-box search and the highest difficultly level involves eight-box trials. Participants can use a (self-initiated) strategy to aid performance, for example, always starting at top left of the array of boxes moving across to bottom right. A Strategy Score is calculated based on how often a searching sequence was initiated from the same box during a trial (Fray & Robbins, 1996). A higher Strategy Score therefore indicates a lower use of strategy.

Delayed STM

The DMtS task assesses the ability to remember the visual features of a complex abstract target stimulus and to select from a choice of four patterns after a variable delay (patterns appear immediately in a '0 delay' condition, or after 4 or 12 s). This task provides an index of delayed short-term functioning.

Procedure

The participants performed the tasks across three sessions with the order of tasks counterbalanced. These sessions were timetabled approximately 1 week apart.

The CANTAB tasks were presented on a high-resolution colour monitor utilizing a touch sensitive screen. The WM and R/K tasks were performed on the same machine that participants performed using a stimulus–response (SR) box.

R/K task training and instructions

All participants received training on the R/K task at the beginning of the testing session that involved the EM task. Children received extensive training as to what the R/K procedure involved and the experimenter ensured all children understood the task instructions before commencing testing whereby each child provided clear examples to verify their understanding. The R/K task was performed using an SR box with buttons labelled to indicate the responses (old/new; remember/know/guess, left/right/something else). Participants first performed a practice testing session with the task requirements described prior to the study and test phases as appropriate. Instructions for R/K judgements were adopted from Gardiner and Richardson-Klavehn (2000). Prior to the practice test phase, the experimenter asked the child if they could explain the difference between 'Knowing' and 'Remembering' a picture. At this stage, most of the children could explain the difference between the two. Any children who were not perfectly clear as to the difference at this stage were given a further explanation whereby the experimenter used examples from everyday life. In this case, the experimenter would ask 'have you ever seen somebody and you knew them from somewhere, but you couldn't remember their name, or where you had seen them before?' You might think 'I know him from somewhere, but I can't remember where', but other times you see someone and might remember 'oh, that's John from school, he sits on my left in class . . . , so you'd say that you remember him'. After the practice test phase, the experimenter again asked each participant to explain the difference between 'Remember' and 'Know' relating to the pictures they had just responded to.

Statistical analysis

All analyses were conducted using SPSS for Windows (v.16, SPSS Inc., Chicago, IL.).

EM data were analysed using univariate Analyses of Variance (ANOVAs) with a between-subject factor of group (with five levels: 8-, 9-, 10-, and 11-year-olds, and adults) conducted separately on hits, correct rejections, false alarms, remember responses, know responses, guess responses, and left/right judgements. Analyses of remember and know responses were conducted in line with similar studies with children (e.g., Billingsley *et al.*, 2002). Thus, remember, know, and guess responses were first adjusted to remove those arising from false positives and then calculated as a proportion of hits rather than of the total (correct and incorrect) of old/new responses. Left/right responses are reported as a proportion of corrected remember responses. Signal detection measures *d*-prime (sensitivity) and criterion were also calculated and were subjected to ANOVAs comparing group performance. WM data were also analysed with factor of group. On all measures only significant effects ($p < .05$) for main effects of group and interactions related to within-subject variables included in the repeated measures design (e.g., difficulty level SWM) are reported. Analyses on the DMtS task were conducted separately on simultaneous and delay conditions in line with other studies (e.g., Rhodes *et al.*, 2004, 2005, 2006). Data from repeated measures ANOVAs report degrees of freedom and F values with the Greenhouse Geisser correction where appropriate. Following ANOVA, least significant difference (LSD) *post hoc* analysis was used, with $\alpha = 0.05$ unless otherwise indicated. Bivariate Pearson correlations were conducted between significant EM and WM measures with $\alpha = 0.01$ to account for multiple comparisons. Mean test scores and main statistics on the EM and WM tasks are presented in Table 2 and significant correlations are shown in Table 3.

Results

Episodic memory data

Accuracy

An ANOVA on hits for old responses revealed a significant effect of group [$F(4,119) = 3.99, p < .005$]. *Post hoc* tests revealed that 8-year-olds had significantly lower hits than 11-year-olds ($p < .01$) and adults ($p < .001$). Adults also had significantly greater hits than 9-year-olds ($p = .05$) and 10-year-olds ($p < .01$). Analyses of correct rejections and false alarms revealed no significant effect of age group. Analyses of signal detection measures revealed significant group differences for *d*-prime sensitivity [$F(4,119) = 5.92$, $p < .001$) but not criterion. Sensitivity was poorer in 8-year-olds than 9- and 11-year-olds

Table 2. Summary of episodic and working memory data

Measure	8	9	10	11	Adult	*F* value	*p* value	*Post hoc* summary
Hits	78	84	82	87	91	3.99	$p < .005$	8 < 11 and adults Adults > 8, 9,10
Correct rejections	91	94	93	94	96	1.62	NS	NS
False alarms	5.6	3.5	4.5	3.9	2.5	1.62	NS	NS
Remember responses*	63	65	61	74	83	4.01	$p < .007$	11 > 10 Adults > 8, 9, 10
Know responses*	24	25	33	20	15	2.91	$p < .03$	Adults, 11 < 10
Guess responses*	12.8	9.6	5.5	5.5	1.7	4.33	$p < .003$	8 > 10, 11, adults Adults < 8, 9
L/R accuracy*	82	91	84	85	93	2.01	NS	NS
d-Prime	2.3	3.0	2.7	3.1	3.5	5.92	$p < .001$	8 < 9, 11, and adults Adults > 8, 9, 10
Criterion	.32	.31	.31	.23	.12	1.59	NS	NS
Verbal STM	80	83	91	90	96	13.03	$p < .001$	8, 9 < 10, 11, adults Adults > all child groups
Spatial span	5.4	5.8	6.0	6.2	7.1	7.68	$p < .001$	8 < 11 and adults Adults > all child groups
Verbal executive WM	65	69	75	81	96	17.95	$p < .001$	8 < 10, 11, adults 9 < 11, adults Adults > all child groups
SWM: between search errors (across 4, 6, 8 box difficulty levels)	15.0	12.2	10.6	9.6	3.4	21.5	$p < .001$	8 < all groups adults > all child groups
SWM: strategy	36	35	32	34	27	14.84	$p < .001$	8 < 10 and adults 9 < 10 Adults > all child groups
DMtS simultaneous (%)	97	92	94	96	99	NS	NS	NS
DMtS delay (% across delays)	72	77	80	87	92	10.6	$p < .001$	8 < 10, 11, adults 9 < adults 10 < 11, adults 11 > all child groups Adults > 8, 9, 10

*Remember, know, guess, and left/right responses are corrected according to hits and false alarms (see statistical analysis section).

Table 3. Significant ($p < 0.01$) correlations between key episodic and working memory measures

Age	Measure	Verbal STM	Spatial Span	Verbal WM	Spatial WM	DMtS
8	All N.S.					
9	All N.S.					
10	Hits			0.59		0.56
10	*d*-Prime					0.63
10	Remember					
10	Know					
11	Hits			0.52		
11	*d*-Prime			0.52		
11	Remember					
11	Know					−0.56
Adults	Hits				−0.56	
Adults	*d*-Prime				−0.56	
Adults	Remember					
Adults	Know					

and adults and indeed all child groups with the exception of 11-year-olds were poorer in sensitivity than adults (see Table 2).

An ANOVA on corrected remember responses revealed a significant effect of group [$F(4,119) = 34.01$, $p < .004$]. *Post hoc* analysis revealed that adults made significantly more remember responses than 8-, 9-, and 10-year-olds (all $p < .01$) but there was no significant difference between 11-year-olds and adults. Eleven-year-olds made more remember responses than 10-year-olds ($p < .05$). An ANOVA on corrected know responses revealed a significant effect of group [$F(4,119) = 2.91$, $p < .03$]. *Post hoc* analysis revealed that adults made significantly fewer know responses than 10-year-olds ($p < .001$), with a trend for fewer responses for adults than 9-year-olds ($p = .07$) and 8-year-olds ($p = .087$) but there was no significant difference between 11-year-olds and adults. Eleven-year-olds gave fewer know responses than 10-year-olds. An ANOVA on corrected guess responses revealed a significant effect of group [$F(4,119) = 4.33$, $p < .003$]. *Post hoc* analysis revealed that 8-year-olds made more guess responses than 10- and 11-year-olds and adults (all $p < .05$). Adults made fewer guess responses than 8- and 9-year-olds ($p < .05$) and did not differ from 10- and 11-year-olds. There was, however, no significant effect of group on left/right accuracy judgements, calculated as a proportion of genuine remember responses [$F(4,119) = 2.01$, $p > .05$]. Summary data are reported in Table 2. In summary, developmental changes in the engagement of episodic retrieval processes were observed across the period of middle childhood with 11-year-olds performing similarly to adults on some episodic measures.

WM data

WM component tasks: short-term storage

An ANOVA on the verbal STM component task revealed a significant effect of group [$F(4,119) = 13.03$, $p < .001$]. *Post hoc* tests revealed developmental improvements across all age groups (all $p < .05$) with the exception of non-significant differences between 8- and 9-year-olds and 10- and 11-year-olds (all $p > .05$).

An ANOVA on span length on the SSP task revealed a significant effect of group [$F(4,119) = 7.68$, $p < .001$]. *Post hoc* tests revealed that 8-year-olds had a shorter span length than 11-year-olds and adults. The adult group had a significantly greater span length than all of the child age groups (all $p < .01$). In summary, children showed developmental changes in storage aspects of verbal and spatial WM, with all child age groups showing poorer performance to adults.

WM component tasks: executive

An ANOVA on accuracy data on the verbal executive WM component task revealed a significant effect of group [$F(4,119) = 18.0$, $p < .001$]. *Post hoc* tests revealed developmental improvements across all age groups (all $p < .05$) with the exception of non-significant differences between 8- and 9-year-olds, 9- and 10-year-olds, and 10- and 11-year-olds (all $p > .05$).

A repeated measures ANOVA on BSEs on the SWM task including a within-subject factor of difficulty level (four, six, eight boxes) revealed a significant effect of group [$F(4,110) = 20.84$, $p < .001$] and a significant interaction between group and difficulty level [$F(5.9, 162.5) = 11.76$, $p < .001$]. *Post hoc* tests revealed that the effect of group reflected developmental improvements in WM across the age groups (all $p < .05$) with the exception of non-significant differences between 9-, 10- and 11-year-olds (all $p >$ .05). The significant interaction between difficulty level and group was followed up with separate ANOVAs at each level with associated follow-up *post hoc* tests. An ANOVA at the four-box stage revealed a significant effect of group [$F(4,119) = 3.62$, $p < .008$]. *Post hoc* tests revealed that 8-year-olds made more BSEs than 10- and 11-year-olds and adults (all $p < .05$). An ANOVA at the four-box stage revealed a significant effect of group [$F(4,119) = 3.62$, $p < .008$]. *Post hoc* tests revealed that 8-year-olds made more BSEs at the four-box stage than 10- and 11-year-olds and adults and adults additionally showed fewer errors to 9-year-olds (all $p < .05$). An ANOVA at the six-box stage revealed a significant effect of group [$F(4,119) = 15.06$, $p < .001$]. *Post hoc* tests revealed that 8-year-olds made more BSEs at the six-box stage than 10- and 11-year-olds and adults. The adult group made fewer errors than all of the child age groups (all $p < .05$). An ANOVA at the eight-box stage revealed a significant effect of group [$F(4,119) = 17.6$, $p < .001$]. *Post hoc* tests revealed that 8-year-olds made more BSEs at the eight-box stage than all other child groups and adults (all $p < .05$). The adult group made fewer errors than all of the child age groups (all $p < .05$), see Table 2.

An ANOVA on Strategy Score on the SWM task revealed a significant effect of group [$F(4,119) = 14.8$, $p < .001$]. *Post hoc* tests revealed that 8-year-olds had a higher Strategy Score indicating a lower use of strategy than 10-year-olds and adults (all $p < .05$) and 9-year-olds had a higher Strategy Score than 10-year-olds and adults (all $p < .05$). The adult group had a lower Strategy Score than all of the child age groups (all $p < .05$). In summary, developmental changes in verbal and spatial executive WM and strategy use to support WM were observed across the age groups with all child age groups showing poorer performance to adults. Younger children (8- and 9-year-olds) also seemed to rely less on using a strategy than older children and adults.

Delayed short-term memory

An ANOVA on percentage of correct responses during the simultaneous condition of the DMtS task revealed no significant main effect of group ($p > .05$). A repeated measures ANOVA on percentage of correct responses during the delay conditions (0, 4, 12 ms) of the DMtS task revealed a significant main effect of group [$F(4,110) = 10.6, p < .001$]. *Post hoc* tests revealed developmental changes with increased accuracy with increasing age across age groups (all $p < .05$) with the exception of no significant differences between 8- and 9-year-olds, 9-year-olds with 10- and 11-year-olds, and 11-year-olds compared to adults (all $p > .05$), see Table 2. These data suggest that children have the ability to hold information in memory over a delay at adult levels by age 11.

Correlational data between episodic memory and working memory

Bivariate Pearson correlations were conducted between key EM and WM measures on which developmental differences were reported. This involved the following EM measures: hits for old responses, proportion of corrected remember responses, proportion of corrected know responses, and the following WM measures: percentage of correct responses on the verbal STM component task, span length on the SSP task, percentage of correct responses on the executive verbal WM task, total BSEs and Strategy Score on the SWM task, and percentage of correct responses across the delay conditions of the DMtS task. Correlations were conducted separately on each age of the five groups.

Correlational analyses on data for 8- and 9-year-olds revealed no significant relationships between EM and WM measures. Analyses on data for the 10- and 11-year-olds revealed significant correlations between EM performance and both the executive verbal WM task and delayed STM task. Analyses on data for 10-year-olds revealed several significant correlations between accuracy on the EM task and WM measures. Hit rate accuracy was positively related to accuracy on the executive verbal WM task ($p < .01$). Ten-year-olds also showed significant positive correlations between hits and *d*-prime and performance of the delay conditions of the DMtS task ($p < .01$). Analyses on data for 11-year-olds revealed significant correlations between accuracy and specific episodic retrieval measures and WM measures. Hit rate accuracy and *d*-prime were both positively related to accuracy on the executive verbal WM tasks ($p < .01$). Accuracy on the delay conditions of the DMtS task was negatively correlated with the proportion of know responses, see Table 3.

Correlational analyses on the adult group data also revealed significant correlations between accuracy and specific episodic retrieval measures and WM measures, although in contrast to children these correlations were significant for the spatial executive WM task. Hit rate accuracy and *d*-prime were negatively correlated with errors on the SWM task in the adult group ($p < .01$), showing that for adults EM performance relates to executive spatial WM.

Discussion

This study has revealed a distinct pattern of developmental changes in the engagement of episodic retrieval processes during the period of middle childhood. Unlike younger children, 11-year-olds engaged recollection to the same degree as adults. Developmental improvements in hit rate accuracy were observed on the EM task; 8-year-old children were less accurate than 11-year-olds and adults and indeed all child age groups with the exception of 11-year-olds were less accurate than adults. Inspection of the engagement of the retrieval processes of familiarity and recollection revealed that unlike children in all of the younger groups, 11-year-olds made a similar proportion of remember responses to adults. Ten-year-olds in contrast showed an increased reliance on familiarity with more

'Know' responses than both 11-year-olds and adults. The present findings suggest that by age 11 children engage episodic retrieval processes in the same manner as adults. The study also reports developmental changes in verbal and spatial storage and executive aspects of WM across middle childhood with all child age groups showing poorer performance to adults. In contrast, 11-year-olds performed similarly to adults on a delayed STM task requiring the ability to hold information in memory over a delay. Interestingly, children aged 8 and 9 years old showed no significant relationships between EM and WM performance while 10- and 11-year-olds showed significant relationships between EM measures and verbal WM specific to the central executive component of verbal WM. Adults showed a contrasting domain related pattern of correlations with significant relationships observed between EM measures and spatial executive WM.

The current findings add to the previous literature (Billingsley *et al.*, 2002; Brainerd *et al.*, 2004; Cycowicz *et al.*, 2003; Defeyter *et al.*, 2009; Ghetti & Angelini, 2008; Holliday, 2003) in identifying the specific ages at which changes in the engagement of episodic retrieval processes occur. Like Billingsley *et al.* (2002) the current study reports such changes using an EM task that provides subjective measures of familiarity and recollection. Billingsley *et al.* (2002) reported that 8- to 10-year-olds had a lower proportion of remember responses than adolescent participant groups aged 14–16 and 17–19 years. Analysis of know responses revealed that 8- to 10-year-olds had a higher proportion of correct know responses than the adolescent groups. The present study builds on these findings in showing significant changes in recollection and familiarity between the ages of 10 and 11 with a reduced reliance on familiarity and increased engagement of recollection. Importantly, the inclusion of a guess response revealed that the youngest children (8-year-olds) who had shown the poorest hit rate on this task also made more guess responses than older children and adults while 10- and 11-year-olds did not differ in proportion of guess responses to adults, showing that younger children used the guess option more frequently than older children and did not rely on know responses for guessing. Surprisingly, 10-year-olds were the only age group to differ from 11-year-olds and adults in the proportion of know responses they made. The inclusion of a guess option may have encouraged 8- and 9-year-olds to choose guess unless they were highly confident they had encountered the item before. In contrast, 10-year-old children, while showing the same levels of accuracy as 8- and 9-year-olds, made few guess responses and did not differ from older children and adults in this respect. It seems plausible that 10-year-olds may have been more confident than younger children that they encountered the item before and consequently made a higher proportion of know responses. Further research using different methodological designs is warranted to clarify developmental trends in familiarity responding. That said, the current findings do suggest that a lack of significant differences reported in the Billingsley study in the proportion of remember and know responses between 8- to 10-year-olds and 11- to 13-year-olds may reflect power issues and know responses at floor levels, rather than a lack of developmental changes during these time points. Previous ERP findings (Cycowicz *et al.*, 2003) have suggested that children aged 9–10 and 12–13 rely on different neuronal networks when retrieving episodic information. The current findings show that future research incorporating imaging methodologies, tasks that incorporate both objective and subjective episodic retrieval measures, and comparison of child participants at specific ages during middle childhood and early adolescence is warranted.

The present study also assessed performance on a range of WM measures namely WM component and delayed STM tasks, and related performance on the EM task to functioning on these tasks. All child groups were less accurate than adults on verbal and spatial storage and central executive tasks. Correlational analyses revealed that younger children (aged 8 and 9 years) showed no significant relationships between EM and WM measures. In contrast, a specific relationship between EM performance and executive aspects of verbal and spatial WM was observed in older children (10 and 11 years) and adults. Interestingly, these relationships showed a domain difference between children and adults, with 10- and 11-year-olds showing positive relationships between EM and verbal executive WM while adults showed this relationship with executive spatial WM. While few studies have examined the relationship between working and EM in children, a recently published study similarly reported a significant relationship between WM capacity and quantity of information retrieved from long-term memory in children aged 9 and 11 (Roderer & Roebers, 2009). The current study builds on this in suggesting a specific relationship between EM and the executive component of WM in children. The current study also reported that 8- and 9-year-olds were less likely to use a strategy to aid performance on an executive WM task (SWM task) than older children and adults. Collectively, these findings suggest that use of strategies to aid memory improves during middle childhood and importantly these improvements are related to the ability to retrieve information from long-term memory. The study also reports that improvements in EM during middle childhood are related to improvements in verbal executive WM suggesting the possibility that use of verbal strategies is related to improved EM performance.

A potential explanation for the lack of significant correlations between EM and verbal executive WM in 8- and 9-year-olds (unlike older children), is that children from 10 years onwards may sub-vocally label, and possibly rehearse, the study images hence relying on verbal executive WM to support performance. It has previously been reported that at around the age of 8 years, children begin to exhibit consistent word length effects and phonological similarity effects even when material is presented in a non-verbal form (Halliday & Hitch, 1988). Interestingly, Marshall *et al.* (2002) interpreted laterality differences between child and adult ERP responses as reflecting the additional verbal naming strategies that they speculated adults engaged in when remembering pictorial items whereas they inferred children relied solely on non-verbal codes. The present study suggests the possibility that it is only round the age of 10 years that children use verbal information to aid memory performance on an episodic retrieval task. It would follow that a lack of such labelling in 8- and 9-year-olds may contribute to poorer retrieval of the image at test. Future research is warranted to investigate these possible relationships between verbal rehearsal and memory performance. It would be interesting, for example, to examine the performance of children in this age range on an EM task with abstract images (which are not possible to label). There is indeed some evidence that private speech is related to performance on a cognitive planning task in 5- and 6-year-old children (Ferneyhough & Fradley, 2005). Further research is required to address the specific role of private speech in aiding long-term memory in children.

The pattern of significant correlations observed between WM and EM is particularly interesting given the recent revision of Baddeley's WM model to incorporate an episodic buffer (Baddeley, 2000, 2007). The current study reports that children and adult's EM is selectively related to executive verbal and spatial WM components with no significant relationships found between EM and verbal and spatial STM measures. This finding supports the original conception of the model that proposes that information is processed between the central executive and episodic long-term memory rather than *via* the verbal and spatial storage systems (Baddeley, 2000). The findings further suggest that children and adults may rely on differing executive strategies to support episodic retrieval. In contrast to children, adults in the current study showed significant correlations between EM measures and executive spatial WM suggesting that adults may use alternative strategies to children when engaging EM. One possible explanation of the current study findings is that adults focus on using a strategy of remembering the location of the object on the screen at study over using a strategy to remember the specific item (i.e., as children may do with a verbal strategy) and hence in adults accuracy on the task relates significantly to visuo-spatial executive WM. It should be noted that the EM task employed in the current study was visual/spatial in nature. Future research can identify whether the same pattern of correlations between verbal and spatial WM in children and adults would be observed using a verbal episodic task (e.g., involving auditory word lists). The verbal and spatial WM tasks also differed considerably in relation to their response measures. The verbal tasks required a match/non-match decision while the spatial tasks involve a reproduction of the to-be-remembered item (SSP) and a complex search task (SWM). These task differences may have influenced the correlations reported. Nonetheless, it is interesting that children and adults showed a differential set of relationships between the current visual/spatial episodic task and aspects of WM and all were assessed on the same tasks. It therefore seems plausible that children and adults may rely on different strategies to aid memory retrieval.

Developmental improvements were also observed in the ability to hold information in memory over a delay (DMtS task), but for this measure 11-year-olds performed at adult levels. Ten- and eleven-year-olds showed significant correlations between EM accuracy and know responses and accuracy on this delayed STM task. The findings presented here suggest that the ability to hold information over a delay may relate to developmental changes in reduced reliance on familiarity when retrieving information from EM. Interestingly, unlike their performance on all other WM measures, 11-year-olds did not differ from adults in performance on the delayed STM task supporting the idea that the ability to hold information in memory over time is important to developmental improvements in long-term memory retrieval.

While the design of the current study has enabled the comparison of EM and WM performance at specific time points during middle childhood, the study is limited by the narrow age range. Other studies, which have incorporated wider age spans, suggest developmental changes in the engagement of recollection and familiarity from earlier in middle childhood into adolescence (e.g., Ghetti & Angelini, 2008). While we have been able to show that 11-year-olds perform at adult levels on the EM task, they did show significantly poorer performance in verbal and spatial storage and executive WM to adults. Investigation of the relationship between episodic retrieval and WM into adolescence is thus warranted to fully investigate the developmental changes in the relationship between these short and long-term memory systems. Furthermore, it is well established that children show developmental changes across the period of middle childhood and early adolescence in a wide variety of aspects of executive function beyond WM to include inhibition, attentional flexibility, and planning (e.g., Luciana & Nelson, 1998). A number of source memory studies have indeed reported relationships between source memory accuracy and aspects of executive functioning including verbal fluency and attentional flexibility (e.g., Drummey & Newcombe, 2002; Rybash & Colilla, 1994; Sluzenski *et al.*, 2004). The current findings indeed suggest that children's use of strategies is related to retrieving information about episodes they have experienced in the past. Future research endeavours can facilitate broader insights into the relationship between the development of executive functions beyond WM and the specific engagement of episodic retrieval processes.

In conclusion, the findings support previous findings of improvements in episodic retrieval processes during middle childhood and suggest that by age 11, children engage episodic retrieval processes in the same manner as adults. The findings also suggest that age-related improvements in EM may relate to specific underlying changes in verbal executive aspects of WM and improvements in the ability to hold information in STM over a delay.

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