

## Increasing Children’s Working Memory Capacity: Preliminary Evaluation of a Card-Based Programme

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### Abstract

Working memory (WM) is recognised as universally foundational to children’s learning. While computerised training programmes can increase working memory capacity, their application in school contexts may be limited by resources and pedagogy, which may restrict use to pupils with the greatest difficulty. This research presents findings from a preliminary evaluation into the effectiveness of a novel, six-week, whole-class working memory programme, which involved pairs of children undertaking daily card-based activities within a single mainstream primary school classroom, involving 24 eight- and nine-year-old children. Post and follow-up measures demonstrated significant gains in children’s working memory and verbal short-term memory, with large effect sizes. While promising, these results should be interpreted with caution due to the sample size and age of participants. Before it can be concluded that this working memory training programme holds potential to increase children’s capacity to learn and achieve, further research needs to establish its usefulness for children with the most prominent WM difficulties, justify its application for children without WM difficulties and eliminate the possibility that gains could have occurred as a result of task-specific learning.

### Keywords

working memory, verbal working memory, whole-class intervention, card-based intervention, collaborative learning.

### Introduction

The most influential and scientifically defensible model of working memory (WM) has been advanced by Baddeley and colleagues (Baddeley, 2001, 2010; Baddeley & Hitch, 1974). This multi-component model of WM demonstrates a flexible system, consisting of four interconnected but functionally distinct subcomponents. The model proposes that the Phonological Loop and Visuospatial Sketchpad are responsible for the storage of auditory and visual information respectively, while the Episodic Buffer stores information from different modalities to allow for a multi-dimensional coding that binds information into an integrated episodic memory. Fundamental to WM is the Central Executive, which controls higher-level attentional and executive processes that process and transform the information stored within these subsidiary systems.

The ability of WM to store and process information provides us with the unique capacity to develop and employ a wide variety of human cognitions. For instance, WM is essential to remembering plans and others’ instructions, considering alternatives and making mental calculations, multi-tasking, and relating to the present, future or past. It also directly links with longer-term memory systems to acquire permanent knowledge. WM is key to the capacity to learn (Alloway, Gathercole, Kirkwood, & Elliott, 2009) and is so integral to functioning in daily life that it has been strongly implicated as a central component of human consciousness (De Gardelle & Kouider, 2009).

The proficiency of WM develops considerably from preschool through adolescence. There is a linear increase in WM performance between 4 and 12 years, levelling off towards 15 years (Gathercole, Pickering, Ambridge, & Wearing, 2004; Pickering & Gathercole, 2001). This maturation in proficiency corresponds to changes in fronto-parietal grey matter structures and their white matter inter-connections (Thomason et al., 2009). However, there is a substantial degree of individual variability

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in WM abilities. For example, a typical class of nine-year-old children is likely to include individuals whose WM capacities vary from that of the average performance of seven- to twelve-year-olds (Gathercole et al., 2004).

WM is implicated in providing a foundational ability on which children achieve many important educational skills. In particular, there is substantial evidence of a causal relationship between children's WM abilities and their attainment in school. For example, children's WM capacity is fundamental to their achievement in key academic domains such as reading (Swanson, Xinhua, & Jerman, 2009), spelling (Ormrod & Cochran, 1988), reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009) and mathematics (Swanson & Kim, 2007). Assessment of WM between the ages of 29 and 41 months is also an excellent prospective indicator of classroom engagement, number knowledge and receptive vocabulary at 74 months of age (Fitzpatrick & Pagani, 2011). Furthermore, in a longitudinal study, Alloway and Alloway (2010) demonstrated that measures of five-year-olds' WM can be a better predictor of academic success at age eleven than measures of general intelligence.

An estimated ten to fifteen per cent of school-aged children experience WM limitations that are sufficient to impact significantly on their educational functioning.

Indeed, as illustrated in Figure 1, these limitations in working memory capacity have wide-ranging observable impacts on children's learning, achievement and classroom functioning. However, these difficulties are often misinterpreted as more generalised attention or intelligence difficulties (Gathercole, Lamont, & Alloway, 2006).

Figure 1. Six difficulties indicating poor working memory capacity in children

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|----|---|
| 1. | Remembering and following spoken instructions                     |
| 2. | Completing tasks that have more than one step                     |
| 3. | Finding mental calculations difficult for their age               |
| 4. | Making choices or decisions                                       |
| 5. | Problem solving that requires holding information in mind         |
| 6. | Has good ideas but cannot write them down (i.e., dual processing) |

As WM is such a foundational ability, children with poor WM do not often catch up with their peers (Alloway et al., 2009). An abundance of evidence, both from large-scale longitudinal studies (Alloway, 2007; Alloway, Gathercole, Kirkwood, & Elliott, 2008), and from control participants in other WM training evaluation studies (e.g., Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Klingberg et al., 2005; Løhaugen et al., 2011) indicates that, without intervention, children's WM remains stable.

### Working memory training programmes

Until recently, WM appeared to be relatively impervious to influences in general environmental experience and educational opportunity (Engel, Santos, & Gathercole, 2008). However, recent research has suggested that both universal and targeted computerised WM training can significantly improve WM for children with poor WM (Holmes, Gathercole, & Dunning, 2009), children with attention deficit hyperactivity disorder (ADHD) (Bigorra et al., 2016; Kerns et al., 2017); typically developing preschool children (four- to five-year-olds) (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009) and adolescents (Løhaugen et al., 2011). While it has been suggested that claims about the efficacy of some adaptive computerised training programmes might be based on research that is methodologically flawed (Apter, 2012; Redick et al., 2015; von Bastian & Eschen, 2015), the potential for these programmes continues to generate substantial interest (see Shinaver, Entwistle, & Söderqvist, 2014).

While computerised training methods hold promise, there are theoretical limitations to their potential. For example, tasks that purport to invoke verbal WM may actually bear more relation to developing visuo-spatial WM, because responses on computerised tasks are inherently visual in nature (i.e., clicking a response on the computer screen). Indeed it is often found that computerised training leads to greater gains in visuo-spatial WM over verbal WM (Holmes et al., 2009; Holmes et al., 2010; Klingberg et al., 2005; Thorell et al., 2009). While research often notes the importance of verbal WM to children's achievement, the emphasis of these programmes to increase visuo-spatial WM over verbal WM is rarely discussed.

Furthermore, there are practical difficulties with computer-based programmes that may restrict their applicability and uptake within the general classroom context (see Ertmer, 2005; Hermans, Tondeur, van Braak, & Valcke, 2008). The need for computer equipment may restrict their accessibility and restrict use to children experiencing the most pronounced difficulties.

Given that WM has a wide-ranging impact on children's academic performance (cf. Alloway & Alloway, 2010) logically, improving children's WM at a whole-class level would lead to corresponding gains across a range of curriculum areas and make the endeavour of creating a whole-class intervention justifiable. For this reason, the present research aimed to evaluate a novel, whole-class WM training programme that overcomes the limitations of computerised training by engaging children in a socially mediated programme of targeted activities that invoke and stretch their individual verbal WM capacity. To the researchers' knowledge, this is the first and only practical programme that has been designed to specifically improve children's WM on a whole-class level.

### Developing a whole-class WM training programme (MeeMo)

To overcome the practical limitations of computerised training programmes, and to develop a theoretically effective WM training programme which was ecologically valid and feasible in the classroom context, a programme development phase was undertaken within a UK primary school. This included successive focus groups with experienced school-based professionals to ensure the programme was tailored to the contextual realities of the classroom environment. Following this, observations and

discussions were held with small groups of children using the prototype materials. These enabled adaptations to ensure that the programme achieved an appealing format and to establish a programme that children could employ with a good degree of autonomy. The outcome was an adaptive WM training programme named MeeMo<sup>2</sup>.

A priority in developing MeeMo was to ensure it provided an engaging and immersive experience for children. In using any WM training activities, children are inherently required to engage in sustained behavioural and cognitive involvement. A child's level of interest in an activity is central to their subsequent allocation of attention. Recognising that attentional modulation is a fundamental component of WM (Baddeley, 1983, 2010; Norman & Shallice, 1986; Shah & Miyake, 1999), a key prerequisite of MeeMo was that children fully engaged with the activities and employed their full attentional capacity to challenge their WM capacity to their individual level.

Using cards as the main format enabled children to work in pairs at a level commensurate with their individual ability. This also enabled a level of peer interaction, which provided continuous social reinforcement, encouraged extrinsic and intrinsic motivation, and modelled attentive behaviours. Furthermore, MeeMo employed a multi-factorial, variable task-difficulty ratio to help children intermittently challenge the fullest extent of their WM abilities, without feeling overwhelmed or strained by the overall activity.

A summary of the key features of MeeMo is provided in Figures 2, 3 and 4 below.

Figures 2, 3 and 4 about here –

The five WM activities contained within MeeMo (Table 1) were initially developed on principles of Baddeley's WM model (Baddeley, 2001, 2010; Baddeley & Hitch, 1974). All of the WM training activities can be regarded as being fundamentally alike since they seek to engage children in a dual-task paradigm which combines a phonological memory span measure with a concurrent processing task (Turner & Engle, 1989). That is, they require the support of both the phonological loop to retain the original list items in memory, and the central executive to process, manipulate or transform this information in some way based on the individual activity's rules (see Alloway, Gathercole, & Pickering, 2006; Morrison & Chein, 2011; Perrig, Hollenstein, & Oelhafen, 2009; Shipstead, Redick, & Engle, 2012; Swanson, Kehler, & Jerman, 2009). A particular advantage of incorporating multiple activities is that the diversity of training experiences targets the central executive component in differential ways, minimises automatisisation (Morrison & Chein, 2011) and anticipates greater levels of generalisation (Schmidt & Bjork, 1992).

*Table 1. An overview of each activity, the associated tasks and the theoretical rationale*

<b>Activity</b>	<b>Description (The Thinker's task)</b>	<b>Theoretical rationale</b>
1. Order, Order	To listen to a string of letters and numbers, and to recall 1) the numbers in ascending order, and then 2) the letters in alphabetical order.	Related to the Letter–Number Sequencing subtest in the WISC-IV (Wechsler, 2003; see also, Crowe, 2000). Central executive component is sequential categorisation and re-ordering of numbers and letters based on numeric and alphabetic knowledge.
2. Group Up	To listen to a mixture of words from two semantic groups and to recall words from within their respective groups.	Places demands on categorisation of stimuli, but requires abstract semantic categorisation of items. Grouping words into semantic categories is a method frequently employed by those with good STM (Delis, Freeland, Kramer, & Kaplan, 1988; Longenecker et al., 2010).
3. Mix Up	To listen to two lists of words, and to re-order the words so the second list is recalled before the first list.	Takes inspiration from practical and ecologically valid activities in asking children to follow increasingly complex instructions. Such activities have previously been employed as an outcome measurement in WM training studies (see Holmes et al., 2009; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010).
4. Location	To listen to a series of words and recall specific words asked for by their location in that list (i.e., 1st, 2nd ... 6th).	Similar processing demands to the Digit Span Backwards task, where a sequence of digits are presented and the child is required to recall them in reverse order (St Clair-Thompson et al., 2010).
5. Spot the Difference	To listen to two lists of words and identify whether the two lists contained the same words (irrespective of their position). If the lists contained different words, they are then asked which words had changed between the lists.	The central executive component is the sequential comparison, judgement, and localisation of words between each list.

<sup>2</sup> The name MeeMo was chosen following consultation with professionals and children. MeeMo holds phonological similarity with the word "memory" and a phonological latent association with a popular children's film (Nemo).

The present research sought to evaluate the outcomes of MeeMo on children's WM. Accordingly, this can be operationalised as follows: Does a preliminary evaluation of MeeMo in a whole-class context for six weeks demonstrate that it is effective to increase children's WM, both immediately after its implementation and at an eight-week follow-up?

## Method

### Participants

Considering the parameters of  $\beta = .05$ ,  $\alpha = .05$ , correlation among repeated measures of  $\alpha = .88$  (Alloway, 2007a) and an anticipated small to moderate effect size of  $f^2 = .15$  (see Dahlin, 2010; Holmes, et al., 2009; Holmes, et al., 2010b; Klingberg, et al., 2005), the required sample size was  $n = 26$ .

A year four class (age 8 to 9 years) from a UK primary school was chosen to participate in the study. To ensure that there were no carry-over effects of teacher expectations in the set-up and delivery of the programme, the school had not been involved in the development phase of MeeMo. The school was selected purposively from a sample of three schools that expressed an interest in participating in the research, based on the single key criterion that it had the highest overall attendance rates, thereby promoting homogeneity in the quantity of experience with MeeMo.

Reasons for involving a year four class were that the children were not engaged in preparation for any significant assessments; that they were socially mature enough to engage in a pairs-based procedure; and the children involved still had eight years of mandatory education left to benefit from potential increases in WM capacity. All of the children in the class returned consent forms and were included with no further criteria for their inclusion or exclusion (see Ethics section below). The average age of the children was 8 years 7 months ( $SD = 0.27$ ), with an even division of 12 boys and 12 girls. School inspection information described the catchment as experiencing high social and economic deprivation, and the proportion of children accessing free school meals is well above the national average (DfE, 2016). Performance data indicate reading and mathematics performance to be in line with national expectations, with writing somewhat below (Ofsted, 2016). There was a 97 per cent attendance rate during the programme implementation, with no discernible pattern of absences.

### Procedure

To achieve a high level of external validity (the extent to which the results can be generalised to the wider population), there was minimal researcher involvement in the setting up and running of MeeMo, with the main guidance for the teacher provided through a brief written guide. Children engaged with the MeeMo materials for 15 minutes a day, five days a week, for a total of six weeks. When the child was The Thinker, they were considered to be in an active state of training to stretch their WM. Including using each activity twice during the first week, this totalled 210 minutes (three and a half hours) of active practice (i.e., being the Thinker), distributed across 30 sessions. Fidelity was specifically assessed through a teacher diary and three observations by the first author.

### Design

To establish whether MeeMo had the potential to improve children's WM, the design entailed assessing children's WM pre-training (T1), post-training (T2) and at a follow-up eight weeks after the programme had finished (T3). Figure 5 illustrates these assessment points and the related time period intervals. Particular consideration was given to the merits of employing a quasi-experimental control group. However, in addition to the considerable practical implications that this would entail, the uniqueness of the current programme would have caused complications in matching participants on an analogous intervention format, thereby posing considerable threats to internal validity (see Shipstead et al., 2012). In addition, there would be little impact of measurement reactivity from exposure to a pre-test creating carry-over effects (Alloway, 2007). Accordingly, the design held the potential to indicate whether changes in children's WM could be attributed to training through the MeeMo programme. University Research Ethics Committee approval was granted following submission of details of the methodological approach.

Figure 5 about here –

### Materials

Materials were as described in the introduction (see Figures 2, 3 and 4). The rationale and intended procedure of MeeMo were introduced by the class teacher, with the assistance of the researcher to answer any questions the children had. The individual activities were first introduced to the class by the class teacher and first author modelling their use. This was initially supported through the use of a PowerPoint presentation to enable children to see what was on the cards that the Questioner (teacher) was reading aloud to the Thinker (first author), followed by demonstrations without the PowerPoint to enable children to focus more on the interactive process (presentation available from the corresponding author).

### Measures

At each of the three time points (see Figure 5) children's STM and WM abilities were assessed using the Automated Working Memory Assessment (AWMA) (Alloway, 2007). As well as having good test-retest reliability and convergent, discriminate and predictive validity, the AWMA has also proven a useful outcome measurement within the context of previous WM training evaluation studies (Holmes et al., 2009; Holmes et al., 2010). Using the AWMA, children were individually assessed and completed one assessment from each domain of verbal STM (Digit Recall), verbal WM (Listening Recall), visuo-spatial STM (Dot Matrix) and visuo-spatial WM (Spatial Recall).

Each of these specific assessments has sufficiently separate task demands from those presented in the MeeMo activities, thereby demonstrating whether real increases in underlying WM capacity have taken place, as opposed to task-specific transfer from skills practice (see Shipstead, et al., 2012). Nonetheless, it is recognised that multiple measurements of each WM domain

would have proven beneficial to more accurately account for any task-specific overlap or differences with the training programme (see Shipstead, et al., 2012).

These assessments were completed with the first author at each of the three specified time points in a quiet room and during the last week of term or half term. While the assessor was not blind to the training, the automation of this assessment enabled efficient, standardised administration and scoring, as well as increased reliability due to removing any potential administrator bias (see Fitzmaurice, Davidian, Verbeke, & Molenberghs, 2008).

## Results

Preliminary t-test analysis demonstrated that the sample was representative of the population, with pre-training (T1) performance on the assessments being comparable to the AWMA standardisation sample ( $\bar{x} = 102.56$ ,  $SD = 11.35$ , all  $p > .05$ ). Furthermore, while there was little anticipated maturation of children's WM from their environment or educational opportunities over the length of this study (Alloway, 2007; Alloway et al., 2008), standardised scores were employed to minimise any such potential.

Estimates of training effects were achieved through a repeated-measures MANOVA (all assumptions met) with one independent variable of time (T1 [pre-training], T2 [post-training], T3 [follow-up]) and four dependent assessment variables (verbal STM, verbal WM, visuo-spatial STM, visuo-spatial WM). Table 2 shows the means ( $\bar{x}$ ) and standard deviations (SD) for all assessments, along with the mean difference ( $\bar{x}_{diff}$ ) scores between assessment periods (T1, T2 and T3) and associated effect sizes ( $\eta_p^2$ ) where appropriate.

Table 2. Effects of WM training programme on WM assessments.

Assessment	Pre-training (T1)	Post-training (T2)	Follow-up (T3)	T1-T2		T1-T3		T2-T3	
	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}_{diff}$ ( $\eta_p^2$ )		$\bar{x}_{diff}$ ( $\eta_p^2$ )		$\bar{x}_{diff}$ ( $\eta_p^2$ )	
Verbal - STM	103.96 (6.69)	113.75 (6.9)	116.88 (7.35)	9.79*	(0.65)	12.92*	(0.71)	3.13*	(0.17)
Verbal - WM	102.33 (5.53)	112.54 (4.31)	115.29 (4.82)	10.21*	(0.36)	12.96*	(0.56)	2.75	--
Visuo-spatial - STM	99.88 (5.21)	104.42 (5.48)	103.17 (6.44)	4.54	--	3.29	--	-1.25	--
Visuo-spatial - WM	104.08 (5.26)	109.96 (4.88)	109.38 (4.23)	5.88*	(0.26)	5.30*	(0.19)	-0.58	--

Note. \*  $p < .05$ . Effect sizes ( $\eta_p^2$ ) are reported for each significant difference.

There was a significant overall effect of time on children's performance across WM assessments,  $\lambda = .17$ ,  $F(4, 16) = 10.00$ ,  $p < .001$ ,  $\eta_p^2 = 0.83$ . Comparing pre-training (T1) with post-training (T2), it is apparent that there was a significant gross effect of the training, leading to gains in children's verbal STM,  $F(1, 23) = 43.17$ ,  $MSE = 53.30$ ,  $p < .01$ ,  $\eta_p^2 = .65$ , verbal WM,  $F(1, 23) = 12.78$ ,  $MSE = 195.74$ ,  $p < .01$ ,  $\eta_p^2 = .36$ , and visuo-spatial WM,  $F(1, 23) = 8.02$ ,  $MSE = 103.24$ ,  $p < .05$ ,  $\eta_p^2 = .26$ , while there were no significant gains in visuo-spatial STM,  $F(1, 23) = 4.12$ ,  $p > .05$ . Each of these gains across verbal STM, verbal WM and visuo-spatial WM remained significant after the two-month post-training follow-up (T3) (all  $p < 0.5$ ).

Furthermore, a comparison of post-training scores (T2) with follow-up scores (T3) demonstrated no significant decreases in verbal WM,  $F(1, 23) = 2.46$ ,  $p > .05$ , or visuo-spatial WM,  $F(1, 23) = 0.14$ ,  $p > .05$ , with a significant increase in children's verbal STM,  $F(1, 23) = 4.80$ ,  $MSE = 48.81$ ,  $p < .05$ ,  $\eta_p^2 = .17$ .

A significant interaction between the effects of the training and different aspects of WM,  $F(6, 138) = 3.94$ ,  $MSE = 39.16$ ,  $p < .01$ ,  $\eta_p^2 = .146$ , indicated significantly more gains in children's verbal STM than their visuo-spatial STM between pre-training (T1) and post-training (T2),  $F(1, 23) = 5.50$ ,  $MSE = 120.37$ ,  $p < .05$ ,  $\eta_p^2 = .19$ .

## Discussion

The findings of this small-scale study are promising. All of the effect sizes of the WM training programme outcomes were large, substantial and potentially meaningful. Furthermore, they appear to replicate previous research in demonstrating that intensive and adaptive WM training can lead to significant and sizeable increases in STM and WM (see Klingberg, 2010; Morrison & Chein, 2011; Shipstead et al., 2012 for reviews). However, unique to the current research is the suggestion that a non-computerised WM training programme can improve children's WM. Encouragingly, children's verbal STM and verbal WM increased by approximately ten standard score points (a large effect size) over the course of the training programme, with increases remaining significant at follow-up. Additionally, a significant increase in verbal STM at follow-up was observed, suggesting STM can continue to significantly increase post-training.

It is potentially useful to explore what features of MeeMo theoretically contributed to its success in this context to prompt explorations for future comparative research and refinement of these programmes. These will now be addressed in more detail.

## Working memory and attention

There is a clear overlap between notions of WM and attention (Shah & Miyake, 1999). Accordingly, the importance and modulation of attention are frequently considered in evaluation studies of WM training programs. Furthermore, there are emerging indications that those with greater levels of attentional focus during training make the most improvements in WM capacity (Perrig et al., 2009). Specifically, attention is generally viewed as a limited-capacity system which is composed of different mechanisms including attentional switching, selective, and sustained attention (McDowd, 2007). These mechanisms overlap with the proposed functions of the central executive (Fournier, Larigauderie, & Gaonac'h, 2008) and are discussed in the context of WM training programmes below.

Attentional switching describes the situation where the focus of attention is alternated between two or more different tasks, cognitive operations or retrieval strategies (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Accordingly, attentional switching is an important component of any WM training programme (Perrig et al., 2009). However, examination of the verbal and visuo-spatial activities contained within computerised WM training programmes indicates that they are often related to simple span activities where lists of items are presented. Accordingly, it is only when list length increases and overwhelms STM capacity that WM resources are likely to be employed. Therefore, these computerised programmes may primarily target STM rather than WM. In comparison, MeeMo activities necessitate both serial recall of list items and task-specific processing, or transformation of the presented information to achieve the correct response, thereby taxing attentional switching to a higher capacity.

Selective attention: the ability to selectively attend to target information and mental representations while simultaneously inhibiting other automatic goal-irrelevant response patterns, is a key function of successful WM processing (Gazzaley & Nobre, 2012; Miyake et al., 2001). Considering this, it is interesting to note that computerised WM activities present children with opportunities to focus on target information but have no elements that require the active suppression of irrelevant details. In contrast, an unanticipated feature of MeeMo's whole-class design is that a high level of irrelevant speech occurs in the classroom during the time of the training, thereby necessitating children to both selectively attend to their partner whilst blocking out irrelevant noise. This opportunity to simultaneously train selective attention may have been of benefit and could have contributed to the observed increases in the children's performance on WM assessments.

Sustained attention has been described as the ability to continuously attend to information over a prolonged period of time (Leclercq, 2002). With two notable exceptions (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; Van der Molen et al., 2010), computerised training sessions last for a minimum of 29.5 minutes per session (cf. Holmes et al., 2009; Holmes et al., 2010; Klingberg, 2010; Klingberg et al., 2005; Thorell et al., 2009), which would far surpass children's capacity to fully apply their attentional resources. By contrast, MeeMo sessions provided children with an intensive six-minute sessional training period, long enough to maintain full engagement and maximally employ their full WM capacity.

## Motivation and engagement factors

Motivation is the process by which effortful goal-directed behaviour is instigated and sustained (Pintrich, 1999). It is considered important for enabling the active and controlled allocation of attention and WM resources to a task (Sarter, Gehring, & Kozak, 2006). Recognising that increased motivation is positively correlated with successfully achieving on WM tasks (Doviss, Van der Oord, Wiers, & Prins, 2011), it is imperative that children are motivated to fully engage and employ their WM to its fullest capacity during training (see Studer-Luethi, Bauer, & Perrig, 2015). A central prerequisite for a successful educational experience is a social presence (Garrison, Anderson, & Archer, 2000), which often increases children's enjoyment and motivation in activities (Anderson, 2005). While the latter is not achievable through solitary computerised programmes, it is a central feature of MeeMo. The social element of MeeMo also allows for continual sensory feedback from their partners' facial, gestural and postural expressions, serving as a powerful reinforcement to maintain attentional effort and attention (Davidson, Scherer, & Goldsmith, 2003).

The adaptive nature of WM training, where children can constantly work at a level commensurate with their individual ability, is an important feature to enable gains in WM to be achieved (Klingberg et al., 2005). Certainly, computerised programmes hold the capability to employ systematic algorithms which adapt the task difficulty to children's abilities on a trial by trial basis, thereby theoretically stretching their WM capacity to its limits. However, existing computerised programmes tend to incrementally increase difficulty after a set period of tasks, with no variation presented within each difficulty level. In contrast, a variable ratio schedule of task difficulty is a defining feature integrated throughout the MeeMo activities. This variation provides children with a range of experiences during each session, challenging them at differential levels, and increasing engagement.

Enjoyment and other achievement-related emotions are heavily influenced by children's perceived control over the anticipated outcomes from the activity (Pekrun, Frenzel, Goetz, & Perry, 2007). In particular, it has long been recognised that there are joint and synergistic effects between perceived control and levels of autonomy (Deci & Ryan, 2002). While computerised programmes are often set up and reinforced by an adult, MeeMo is run by the children. This autonomy and ownership can lead to higher levels of intrinsic motivation and interest (Tsai, Kunter, Lütke, Trautwein, & Ryan, 2008), and consequently see the application of greater effort to make progress on activities (Ciani, Middleton, Summers, & Sheldon, 2010).

## Self-efficacy and metacognition

MeeMo was carefully designed with the intention to increase children's self-efficacy, confidence and self-awareness, with interview reports from children indicating that children adopted a mastery orientation as their goal with high levels of intrinsic motivation. The factors which are likely to have contributed to this include MeeMo's unique approach to learning and cognitive stimulation providing a gratifying experience. Design-specific features of MeeMo that may have further contributed to this involve it having an overall positive challenge–skill balance with a variable ratio of task difficulty built in, clear feedback through

children accumulating cards and social reinforcement from their partner, personalised goal setting using their monitoring booklets, and ease of use to allow for a high level of autonomy.

The self-efficacy of memory in particular is a strong mediator in explaining performance on cognitive assessments, including assessments of WM (Valentijn et al., 2006; West, Bagwell, & Dark-Freudeman, 2008). Accordingly, it is interesting to note that thoughts of incompetence which often spontaneously arise when confronted with a demanding task reduces WM performance (Autin & Croizet, 2012). This is likely to be due to the provoked feelings of anxiety stimulating a range of thought processes (e.g., how the activity can be avoided), all of which captures WM and restricts the available resources to be applied to the task at hand (Schmader & Beilock, 2011).

The potential effect of such increases in children's self-efficacy, confidence and awareness of their WM capacity is that it helped them to realise more realistically the quantity of information that they can remember and process. In turn, this may increase children's propensity to maximise their WM capacity, not only across the training sessions but also throughout the curriculum and when completing everyday activities (Aunola, Leskinen, Onatsu-Arviolommi, & Nurmi, 2002; Autin & Croizet, 2012). Indeed, recognising the predominantly verbal demands of the classroom (Alloway, 2010; Gathercole, et al., 2006b), this provides children with an opportunity for extended and continual practice of maximising their WM capacity if they feel confident in doing so. Such experience would likely result in a positive feedback loop that continually reinforces and increase WM capacity over time (Bandura, 1991; see also Klingberg, et al., 2005; Shavelson, et al., 2008 for similar considerations). Accordingly, the abundance of practice children potentially experience in continually maximising their WM capacity across contexts could account for the considerable improvements observed in their WM following the training, as well as the maintenance of WM and continued improvements in STM after training had concluded.

### Limitations and future research

While these findings highlight the potential of MeeMo as an effective whole-class WM training programme, it is important that future evaluation procedures make use of more rigorous methodologies which account for other extraneous variables (Moody, 2009; Shipstead, et al., 2012; Sternberg, 2008).

For instance, the current sample consisted of a single classroom unit, making a clear case that the generalisation of these findings needs to be explored through evaluating its implementation with children of variable characteristics (i.e., age, specific conditions), teachers of differing pedagogical dispositions, and schools with diverse ecological factors. Furthermore, due to the lack of control group, it is important that these findings are verified through incorporating an experimental design, ideally in the form of a randomised controlled trial, to accurately control for factors such as maturation, history, measurement reactivity and expectancy effects (Bootzin & Bailey, 2005; Morrison & Chein, 2011). The measurements were not taken blindly, which may have increased potential for researcher bias, although this may have been offset to some extent by using an automated assessment. While the results potentially support previous findings suggesting the universally targeted WM interventions can be beneficial (Thorell et al., 2009; Løhaugen et al., 2011), further research is needed to understand the specific impact that MeeMo can have for the ten per cent of children experiencing a prominent WM difficulty (Alloway et al., 2009). It is also important that future research tracks WM increases at frequent time intervals to identify the rate of progress and highlight potential ceiling effects. Additionally, with the current programme presenting as a novel WM training method, it would be appealing to compare the efficacy and ecological validity of MeeMo with a current computerised equivalent (see Fixsen, et al., 2005; Levin, 2005). In a systematic review of interventions to support children's WM, Randall (2016) noted that there were links between evaluations of Cogmed and the authorship and commissioning of the research. Here too, the first author is the developer of MeeMo (see Disclosure Statement), and this should be considered when evaluating findings. Mindful of this, the authors have strongly encouraged independent research into the efficacy of MeeMo, although to date, these findings, while promising, are again limited to small-scale unpublished studies (Randall, 2016; Walker, 2016).

### Conclusions

The current research suggests the potential of MeeMo as an effective whole-class WM training programme to increase children's WM capacity. It should be noted that, because of the small sample size, further research will be important to demonstrate the generalisation of these findings. Accordingly, it is important that these considerations are validated through further research to assess the subsequent transference of such WM improvements on cognitive capacities (e.g., attention and fluid intelligence), achievement (e.g., literacy, comprehension and maths), as well as daily behaviours (e.g., those relating to ADHD symptomologies and emotional regulation). When evaluating these areas, it will be important to utilise a control-group, longitudinal design that can capture the differential latency periods for any such transference effects (see Shipstead et al., 2012).

Recent research has shown that WM can be meaningfully increased through explicit, systematic and adaptive training techniques. The present research extends this, to show how a practical whole-class WM training programme can provide schools with the prospect of not just teaching to children's underlying capacity but actively increasing their learning capacity. If effective WM training can be made accessible to all, then it holds the potential to increase every child's capacity to learn and achieve.

With approximately ten per cent of children experiencing a prominent WM difficulty (Alloway et al., 2009), there is a significant proportion of children at risk of educational underachievement across reading (e.g., dyslexia) and maths (e.g., dyscalculia), as well as more general topics throughout school (Alloway et al., 2009). As such, educational psychologists (EPs) spend a significant proportion of their time endeavouring to uncover these difficulties through cognitive and neuropsychological

assessment, and work with parents and teachers to evaluate the broad-ranging implications that WM difficulties have across the child's life.

Historically, EPs have helped children to better access the curriculum through consultations on adapting teaching to accommodate and circumvent these difficulties. However, increasing demonstrations that such a fundamental ability can actually be improved offers great prospect to improve these children's lifelong learning outcomes. While WM training programmes like Cogmed and MeeMo hold great promise, the arena of cognitive training remains within its relative infancy. EPs are perfectly positioned to be at the forefront of these programmes' evaluations, and also perfectly primed to develop and pioneer innovative approaches to improve and enhance programmes for the benefit of all children.

### Disclosure Statement

The first author is the creator of MeeMo. Since the completion of this research, MeeMo has become a commercially available product.

Figure 2. Key features of MeeMo working memory training programme

- Uniquely developed as a practical, whole-class working memory training programme.
- Designed as a game to make it an engaging and enjoyable experience for children to use.
- Uses cards which display a question and instructions on the front, and an answer on the back (see Appendices A and B).
- Children work in pairs, taking it in turns to be either:
  - The Questioner who asks the questions and checks the answers.
  - The Thinker who listens to the question and provides an answer.
- Five WM activities (one for each day of the week), thereby facilitating the ease of programme use, and increasing children's engagement.
- Three difficulty levels (easy, medium and hard) for each activity, accommodating the range of WM abilities in the class.
- Employs a multi-factorial, variable ratio of task difficulty within each difficulty level to stimulate engagement, theoretical effectiveness and meta-cognitive awareness.

#### Class Implementation

- Used daily for a six week period.
- Six minutes for each individual session, after which children swap roles (Questioner / Thinker).
- Total class session length is approximately 15 minutes a day.

#### Children's Process

- Thinker receives real-time feedback.
- Thinker's progress is visually tracked in a Personalised Monitoring Booklet.
- Children can select their own difficulty level.

Figure 3. Examples of Each WM Training Activity (Grayscale)

<p><b>Instructions</b> - Listen carefully. Say these numbers back in order from lowest to highest.</p> <p>9   3</p> <p>5  </p> <p>6  </p>	<p><b>Answer ✓</b> - Say the numbers in order.</p> <p>3   9</p> <p>5  </p> <p>6  </p>
<p><b>Instructions</b> - Listen carefully. Remember the words...</p> <p>Car   Boat</p> <p>Blue  </p> <p>Green  </p>	<p><b>Answer ✓</b> - Can you name all of the...</p> <p><u>Colours</u>   <u>Transport</u></p> <p>Blue   Boat</p> <p>Green   Car</p>
<p><b>Instructions</b> - Listen carefully. Say these objects back to me in the right order...</p> <p>Train   Lips</p> <p>Fork   Apple</p> <p>But First...</p>	<p><b>Answer ✓</b> - What was the First (1<sup>st</sup>) word? - What was the Third (3<sup>rd</sup>) word?</p> <p>1<sup>st</sup>   Fish</p> <p>3<sup>rd</sup>   Hat</p>

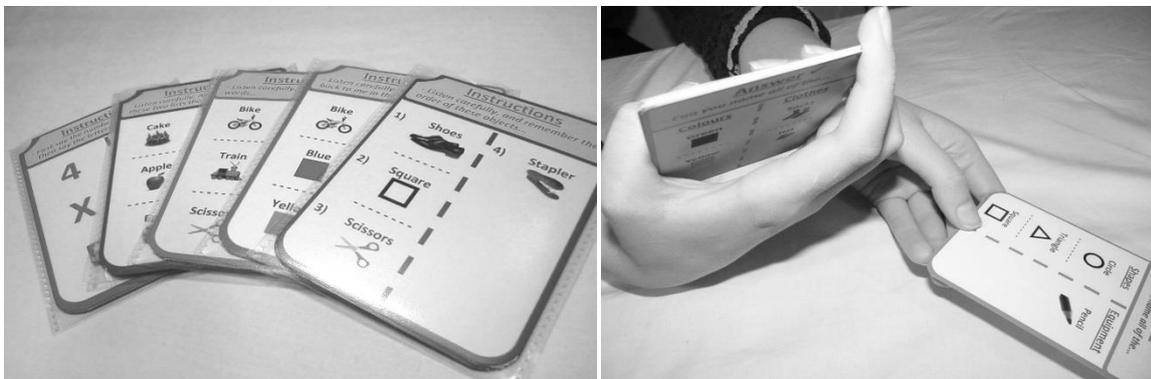
<b>Instructions</b>		<b>Answer ✓</b>	
<i>- Listen carefully. Are the words in these two lists the same or different?</i>		<i>- Do the lists have the same words? - Which two words have changed?</i>	
Eye 	Eye 	Different 	Chair 
Chair 	Egg 		Cat 
Egg 	Cat 		

\*scale 2:3

Figure 4. Photographs of the WM Training Resources (grayscale)

**Design of the Cards**

Illustrating the size and shape, internal and external design of the cards. The cards are grouped in sets of 10s and held within appropriately sized plastic wallets.



**Storage of the Activities**

Illustration of the colour coordinated boxes used to store the WM training programme's resources.



Figure 5. Evaluation of outcomes research design



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