

RESEARCH ARTICLE

Adaptation of the Missing Scan Task to a touchscreen format for assessing working memory capacity in children

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Abstract

Assessing children's working memory capacity (WMC) can be challenging for a variety of reasons, including the rapid increase in WMC across early childhood. Here, we developed and piloted an adapted WMC task, which involved minimal equipment, could be performed rapidly, and did not rely on verbal production ability (to facilitate the use of the task with younger children). In our adaptation, we portrayed the events of the object-based Missing Scan Task (creatures hiding in and emerging from a house) in a touchscreen format. In the full experiment, 67 participants aged 23 to 90 months achieved the longest set size (LSS) scores that were distributed across the full range of possible scores. A comparison of these scores with those obtained using object-based formats indicated general agreement between the versions of the task. Scores were found to increase with child age. We propose this (freely available) touchscreen adaptation as a suitable WMC task for use with children aged 2 to 7 years.

KEYWORDS

children, developmental psychology, preschool, touchscreen, working memory

1 | INTRODUCTION

Working memory (WM) is the capacity to retain and manipulate information over a short period of time (Baddeley & Hitch, 1974; Gathercole, Brown, & Pickering, 2003). Along with inhibition and task switching (or set shifting), it is one of the core executive functions. WM plays a role in capacities such as reading (Savage, Cornish, Manly, & Hollis, 2006), mathematics (Bull, Espy, & Wiebe, 2008), and reasoning (Kyllonen & Christal, 1990; Oberauer, Süß, Wilhelm, & Sander, 2007), as well as school readiness (Fitzpatrick & Pagani, 2012; Swayze & Dexter, 2018) and school achievement (Gathercole et al., 2003).

Children's working memory capacity (WMC) increases over development (Case, Kurland, & Goldberg, 1982; Gathercole, Pickering, Ambridge, & Wearing, 2004). Assessing children's WMC can be challenging for a variety of reasons, however (Roman, Pisoni, & Kronenberger, 2014; Zimmermann, Frank, Subiaul, & Barr, 2021). These include children's developing verbal abilities and their limited interest in tedious or repetitive tasks. In addition, a rapid increase in WMC over childhood years means that older children may perform at ceiling on tasks that are appropriate for younger children and that younger children may perform at floor on tasks that are appropriate for older children.

A number of tasks have been developed to assess children's WMC, many of which involve three-dimensional (3D) objects. These tasks include Spin the Pots (Hughes & Ensor, 2005; Zimmermann et al., 2021), Hide and Seek (Boudreau, Dempsey, Smith, & Garon, 2018; Garon, Smith, & Bryson, 2014), Magic Wand (Boudreau et al., 2018; Diamond, Prevor, Callender, & Druin, 1997), the Imitation Sorting Task (Alp, 1994), and a card-based visual counting span task (Case et al., 1982; Marcovitch, Boseovski, Knapp, & Kane, 2010). Children's verbal WM has been assessed with tasks that involve the verbal repetition of a series of words or digits (Carlson, Moses, & Breton, 2002; Case et al., 1982; Davis & Pratt, 1995), either ordered (forward or backward) or unordered. The age range of children tested with each of these tasks is limited by children's motor development for 3D object tasks and verbal production ability for verbal tasks, meaning that few tasks are appropriate for use across early childhood.

In this study, our aim was to develop a WMC task that can be used across early childhood, which involves minimal equipment, can be performed rapidly enough to be incorporated into a single session with other tasks, and does not rely on verbal production ability. A task that is usable for a range of ages can assist researchers who test children across a wide band of the early lifespan. A touchscreen format could reduce the equipment (and possibly time) requirements for assessing children's WMC. Assessing WMC rapidly, leaving time in a research session for another task, can reduce the number of sessions required for some research or reduce the attentional focus required to complete all tasks of interest, and thereby possibly reduce experimental attrition. A task that minimizes verbal production requirements facilitates working with younger children, whose language comprehension may exceed their production abilities.

We therefore adapted a well-established task from an object-based format to a touchscreen format. Roman et al. (2014) developed the Missing Scan Task for use with children, based on a paradigm for adults developed by Buschke (1963). In the Missing Scan Task, a child is shown groups of stuffed toy characters, starting with a group of two, and asked to name them. The stuffed toys are then moved out of sight into a toy house. After a short delay, one of the toys comes out, and the other one remains in the house. The child is asked to name which toy is still in the house. Trials are structured using a staircase procedure, so that if a child successfully answers a problem with N toys, they are given a new problem with $N + 1$ toys. If they answer unsuccessfully, they are given a new problem with $N - 1$ toys (and usually a floor value is set). This stepwise method allows researchers to pinpoint a child's working memory capacity with precision. For trials with two or more toys, all toys but one emerge from the house at the end, so that a child is always searching for a single missing identity. In the task, children are asked to hold information in memory (the identity of all of the stuffed toys that went in the house) and then to search through this information for the one that is missing when the rest come out of the house. The longest set size (LSS) for which a child can correctly answer the question is the outcome measure, regardless of when it occurs in the experiment (i.e. the trial with the longest set size does not need to be the last trial). This task has been successfully adapted with more compact equipment, including laminated pictures of stuffed toys (Swayze & Dexter, 2018) or small animal figurines

(Grieco-Calub, Collins, Snyder, & Ward, 2019; Jusienė, Rakickienė, Breidokienė, & Laurinaitytė, 2020) instead of the original stuffed toys.

In this study, we first piloted a touchscreen version of the Missing Scan Task with a small group of 3- to 4-year-old children, and then used the final version of the task, which had been updated based on experiences with the pilot version, with children aged 23 to 90 months. Previous research has found that WMC in children increases with age; in order to validate this task, we would expect to find a similar pattern of children's WMC increasing with age. Here, we report the results of this investigation, and how the results compare to the outcomes of object-based versions of the task.

2 | MATERIALS AND METHODS

All phases of the research were conducted in accordance with the British Psychological Society *Code of Human Research Ethics* (The British Psychological Society, 2014).

2.1 | Pilot participants

During the pilot phase of the study, we tested 13 children (7 female), aged 3 to 4 (36 to 57 months), in a university-based kindergarten in the United Kingdom. Parents enrolling their child(ren) in this kindergarten give written consent for the child(ren) to participate in research conducted on-site. Parents are also given the opportunity to opt out of each study; this is carried out by placing study descriptions on a notice board outside the kindergarten entrance and providing opt-out forms, which can be returned to the kindergarten. Any child(ren) opted out of the study by their parent was not asked to participate. A child's assent (to play the game with the experimenter) was requested and obtained before they took part in the study.

2.2 | Main task participants

During the main task phase of the study, we tested 61 children at the Stirling Summer Science Festival, an event advertised to parents by local publicity. Parents gave written informed consent for their child(ren) to participate in the study. From these participants, we were unable to use the data from seven children (two due to parental intervention, one for imprecise tablet operation, one due to being outwith the age range of interest, two for incomplete age information, and one for equipment malfunction).

To balance the age distribution, we also tested 16 children at a primary school in the United Kingdom. Parents gave written informed consent for their child to participate in the study. From these participants, we were unable to use data from three children (two due to being outwith the age range of interest and one due to colour anomalous vision).

Our final sample size included 67 participants (42 female), aged 1 to 7 (23 to 90 months): two 1-year-olds, ten 2-year-olds, seventeen 3-year-olds, sixteen 4-year-olds, ten 5-year-olds, six 6-year-olds, and six 7-year-olds. For the analysis of children's performance by age in years, the 1-year-olds and 2-year-olds are included in a "2-year-old" group.

Although we intended to recruit additional participants to achieve more balanced numbers in each of the age groups, the global SARS-CoV-2 pandemic of 2020 prevented the timely completion of extended data collection.

2.3 | Apparatus

Testing was carried out on a Surface touchscreen tablet (Microsoft, Redmond, WA). The task programme was custom-written in PsychoPy 3 Builder (Peirce et al., 2019).

2.4 | Procedure

The child participant was told they would be playing a game where their job was to remember something. The experimenter and child did one practice trial to familiarize the child with the format of the game. The practice trial had two creatures, and each display transition was controlled with a touch so that the experimenter's narrative instructions could be paced appropriately. After a single practice trial, the child began the task.

In a trial, a number of creatures (identical except for their colour) appeared on the left side of the screen (see Figure 1 for an illustration) for 10 s. All participants started the game with two creatures. These were named by their colour by the experimenter, who explained that they would soon go inside the house, so the child should remember them. The creatures then "went inside the house"; that is, they disappeared from the left side of the screen and their faces could be seen in the house's windows for 2.5 s. Next, the curtains of the house were drawn so that the creatures were not visible for 2.5 s. Finally, all but one of the creatures "came out of the house" on the right-hand side of the screen next to a question mark. This screen was shown for 3.5 s before the final selection screen appeared, which added an array of 10 creatures (main task) or 11 creatures (pilot task) across the bottom of the screen (always in the same order for every trial). The experimenter asked the child "Which one/who is still in the house?". The child was asked to pick from the array by touching the creature of the appropriate colour. Finally, a feedback screen appeared, in which the correct creature's face appeared emerging from the right-hand side of the house. The same (correct) feedback appeared regardless of the child's selection. If the child had selected the correct creature, the experimenter said "That's right, [Green] was the one in the house!". If the child had selected the wrong colour, the experimenter said, "Oh, it was [Green] in the house, what a tricky creature! That's OK, let's do another one." (This was suggested by A. Roman, personal communication, as a way to maintain a positive task experience and progress to the next trial.)

In the selection array, each creature appeared on a background rectangle of the same colour, outlined in either black or white. In the main task, the selection array creatures were orange, yellow, green, white, blue, red, black, pink, brown, and grey (Figure 1); in the pilot, there were 11 colours instead of 10, including those listed above as well as purple. Three of the creature colours—black, white, and grey—from the array were never used as potential target colours in a trial.

After the practice trial was completed (regardless of whether the child had selected the correct creature), the first test trial had two creatures. If the child answered the first test trial correctly, they next got a trial with three creatures. The number of creatures increased by 1 every time the previous trial was answered correctly, up to a maximum of seven creatures (main task) or eight creatures (pilot task). The game ended if the child correctly answered a trial with the maximum number of creatures (seven in the main task; eight in the pilot task). During the game, the number of creatures decreased by 1 every time the previous trial was answered incorrectly, down to a floor of 2 (main task and pilot task). In both versions of the task, the minimum score was 0; this occurred if a child never responded correctly to any trial. See Figure 2 for examples of how the game might proceed.

In the main task, the maximum number of trials allowed was 10, and the maximum number of errors was 4; if either of these was reached, the game ended. In the pilot task, the maximum number of trials allowed was 8, and the maximum number of errors was 3. The reasons for some of the differences between the pilot task and the main task are addressed in Section 3.

At the end of the game, regardless of a child's score, a screen was displayed in which all the creatures were depicted having a party inside the house. The experimenter thanked the child for taking part.

For the test trials, step timings were pre-specified in the programme. The child's response screen was untimed; the trial finished only after the child initiated a touch response to one of the creatures. A "Ready?" screen between trials was also untimed and proceeded on a touch response, so that if necessary, a session could be paused until a participant was ready to continue.

The task does not have any accompanying auditory stimuli. Therefore, we anticipate that this set of creatures can be used across languages, and experimenters can give the creatures any name they choose; we used "Flooven." There is a text-based introductory "Welcome!" screen in the game, a post-practice-trial "Let's get started!" screen, and an introductory "Ready?" screen for each trial; the text for each of these screens is editable in PsychoPy for

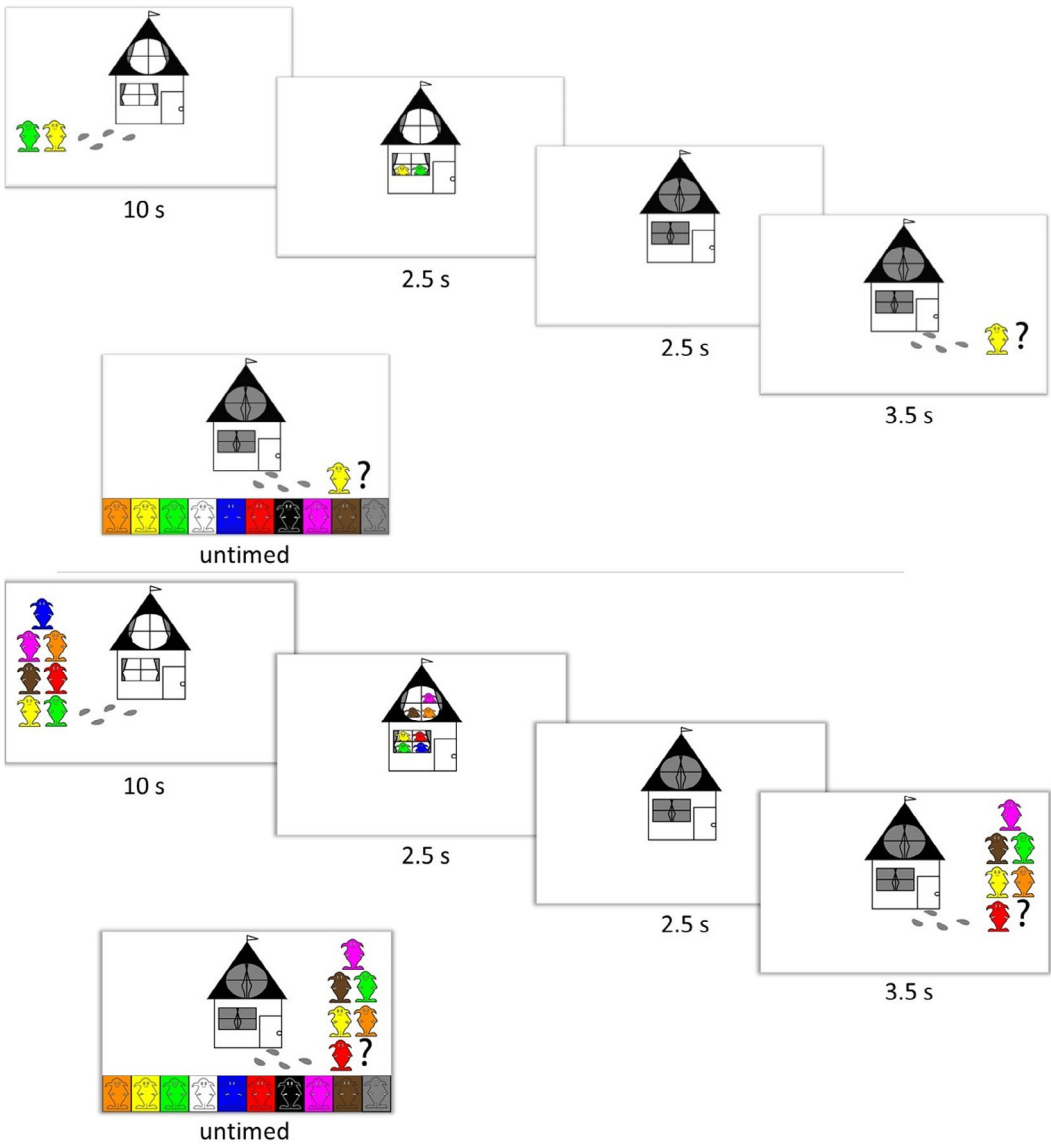


FIGURE 1 (Top) Illustration of the sequence of a two-creature trial. The correct response for this trial would be to select the green creature. (Bottom) Illustration of the sequence of a seven-creature trial. The correct response for this trial would be to select the blue creature

experimenters preferring to use a different language (see the game manual online for instructions). The final screen has “Thank you!” text built into an image file, which is editable using graphics software but not directly in PsychoPy.

2.5 | Variables

The variable of interest was the LSS, which is the total number of creatures in the largest set to which a child responded correctly. If a child never responded correctly to any set, their LSS was 0; if they responded correctly to

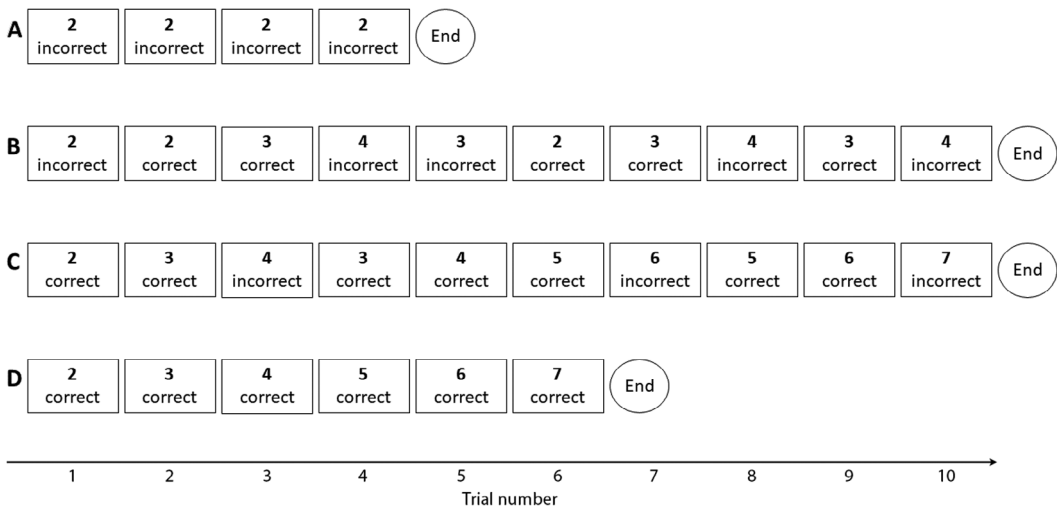


FIGURE 2 Possible trial sequences in the staircase based on performance. (A) If a participant never responds correctly to a two-creature trial, their LSS would be 0. A maximum of four errors can be made before the game ends. (B) If a participant responds correctly to some two- and three-creature (but not four-creature) trials, their LSS would be 3. The game ends after a maximum of 10 trials. (C) If a participant responds correctly to a six-creature trial, but incorrectly to a seven-creature trial, their LSS would be 6. (D) If a participant responds correctly to all trials, their LSS would be 7. The game ends once a seven-creature trial is answered correctly

two-creature problems but incorrectly to three-creature problems, their LSS was 2; if they responded correctly to three-creature problems but incorrectly to four-creature problems, their LSS was 3; and so on.

2.6 | Statistical analysis

Statistical analysis was carried out in R version 3.6.3 (R Core Team, 2020).

3 | RESULTS

In the pilot study, children's LSSs ranged from 0 to 4 (mean, 2.4). Of the participants in the pilot study, 8 of the 13 children made a pink-purple error (selecting the pink creature when the correct answer was purple or vice versa). After pink-purple errors (eight in total), the next most frequent colour combinations for errors were red-blue and pink-red (with three errors each); all other errors were made 2 or fewer times. Because of the seemingly great potential for confusion between the pink and purple creatures (supported by the findings of Wagner, Dobkins, & Barner, 2013), we eliminated the purple creature from the main task and settled on the final parameters (10 creatures; 10 trials or 4 errors allowed) described in Methods.

For the main task, LSS scores were distributed across the full range, including scores of 0 and every possible score from 2 to 7 (overall mean, 4.1); it was not possible to achieve an LSS of 1. Means by age group are presented in Table 1, along with scores from Roman et al. (2014), Swayze and Dexter (2018), Grieco-Calub et al. (2019), and Jusienė et al. (2020). Despite some variation, the results overall accord between the various studies, with scores increasing with child age.

Children's LSS increased with age in months (Figure 3). A Spearman's rank-order correlation between LSS and age in months showed a positive relationship ($r_s = .70, p < .001$).

TABLE 1 Longest set size by age for this and other studies using a similar methodology

| | Longest set size (SD) (n) | | | | | | |
|---|---------------------------|------------------|------------------|------------------|------------------|-----------------|--|
| | 2-year-olds | 3-year-olds | 4-year-olds | 5-year-olds | 6-year-olds | 7-year-olds | |
| This study (N = 67 total) ^a | 1.75 (1.48) (12) | 3.59 (1.87) (17) | 4.12 (1.26) (16) | 5.40 (1.43) (10) | 6.17 (1.33) (6) | 6.00 (1.55) (6) | |
| Roman et al. (N = 40 total) | | 4.10 (1.59) (10) | 5.00 (1.83) (10) | 6.20 (1.93) (10) | 6.80 (2.35) (10) | | |
| Swayze & Dexter (N = 40 total) ^b | | 3.05 (1.03) (29) | 3.27 (1.81) (11) | | | | |
| Grieco-Calub et al. (N = 94 total) ^c | | | 4.11 (1.49) (19) | 4.80 (1.54) (75) | | | |
| Jusiené et al. (N = 181 total) ^d | | | 3.90 (1.46) (90) | 4.86 (1.92) (91) | | | |

^aThe group of 2-year-olds in the present study included two 23-month-olds.

^bData were provided by the authors upon request. This measure was a composite of two Missing Scan Task sessions conducted 1 week apart; in this version of the task, a score of 1 was possible. The mean age of 3-year-olds was 41.7 months, and the mean age of 4-year-olds was 48.8 months.

^cData were provided by the authors upon request. The mean age of 4-year-olds was 59.1 months, and the mean age of 5-year-olds was 62.2 months.

^dData were provided by the authors upon request.

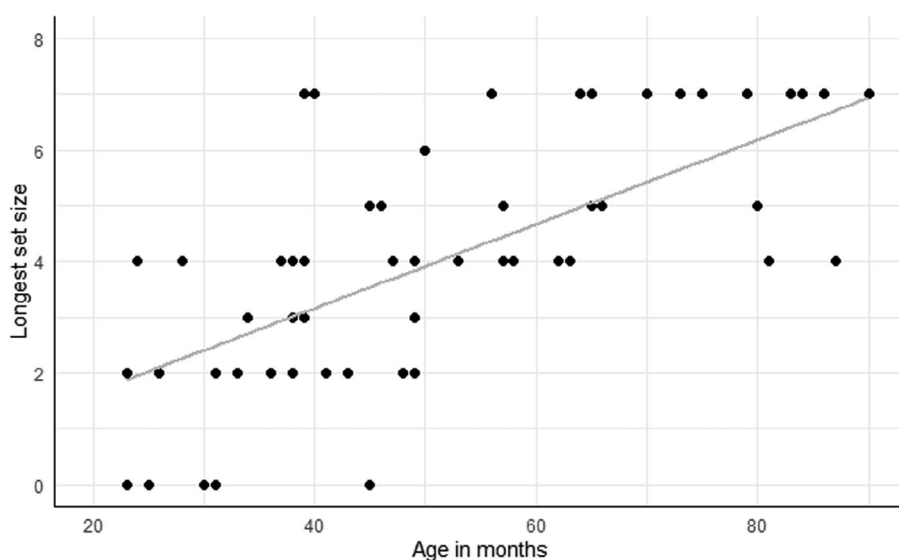


FIGURE 3 Children's performance on the task as measured by longest set size (LSS) and age in months. The trendline is fitted to the data of all ages

4 | DISCUSSION

In this study, we developed a touchscreen version of an established 3D task to evaluate children's WMC. We found that children's working memory scores on the touchscreen Missing Scan Task increased with age. Age-related changes in children's WMC performance accord with the findings of other researchers (Boudreau et al., 2018; Case et al., 1982; Gathercole et al., 2004; Roman et al., 2014; Zimmermann et al., 2021). In addition, the results from this study generally agreed with the results obtained by researchers using object-based versions of the Missing Scan Task.

Therefore, we propose this touchscreen version of the Missing Scan Task as a suitable alternative to object-based versions. Children as young as 2 years and as old as 7 years were motivated and interested to take part in the study. Task completion was fairly rapid, as the total number of trials was limited to 10 and even young children did not lose interest in the game before the trial limit was reached.

This computer programme and associated documentation are available to download at the Open Science Framework (<https://osf.io/jw2er/>).

Because the Missing Scan Task likely accesses components of both verbal and visuospatial working memory (Roman et al., 2014), it is not strictly a measure of one type of working memory. In theory, children could solve this task by using a purely verbal strategy (list of names), a purely visuospatial strategy (remembering the colours of creatures that went into the house), or a combination of strategies. Indeed, each individual might vary in the memory store they would access to solve the game.

One limitation of this study was the sample, which included fewer 6- and 7-year-olds than 3- and 4-year-olds; while we attempted to use this task with as many children in the relevant age range as possible, the global COVID-19 pandemic limited our ability to do so. A useful future arm of research would be to validate the task using established paradigms, ideally by relating within-subjects performance on this task and that on an existing WM task. This may be possible in future research.

Another potential limitation of this method is the imperfect colour labelling skills of preschool-aged children. Children's abilities to comprehend and produce colour labels, as well as match colours without using verbal

responses, have been studied extensively (see for example, Dale, 1969; Heider, 1971). A recent eye-tracking study indicates that children as young as 19 months comprehend some basic colour words, as evidenced by looking more towards an object of a colour labelled verbally by an experimenter (“look at the red chair”) than a differently coloured distractor object (Forbes & Plunkett, 2019). While children's production of colour words tends to lag their comprehension of them (Sandhofer & Smith, 1999), parental reports for British children indicate that more than half of 24-month-olds both comprehend and produce at least four colour labels (Forbes & Plunkett, 2019). Experimental work indicates that children begin to produce adult-like verbal colour labels between ages 2 and 3 years (Wagner et al., 2013). And by the age of 4, children generally show good comprehension and production of colour labels (according to parental reports), and perform well on colour-based behavioural tasks (Forbes & Plunkett, 2019). This fairly early acquisition of colour label knowledge is not restricted to the United Kingdom but rather appears across cultural and linguistic contexts, with some variation between languages (Forbes & Plunkett, 2020). However, the acquisition of accurate colour labels varies by individual and label, so a colour-based WM game may underestimate younger children's working memory abilities.

In addition, the number of colours used in the task is limited by the number of colours which children are able to label consistently. Therefore, results may not reflect children's true abilities at the upper limit. Older children may be able to remember more than seven items at once (the maximum number of creatures in this game): Roman et al. (2014) reported that at least one child each from the age groups of 5 and 6 years remembered 10 animals, the maximum number they were given, while at least one 4-year-old answered accurately with a group of nine animals.

Despite the limitations of a task based on colour knowledge, benefits of the method include the lack of a need for verbal production (possibly improving performance in younger children), the rapidity of administration, and the minimal equipment needed. The non-verbal response method meant that children could use visual colour matching to solve the task and touch to respond on each trial. The minimization of time and equipment needs are useful for those interested in assessing working memory efficiently across a range of ages in children.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available at <https://osf.io/jw2er/>.

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