DOI: 10.1111/infa.12599

RESEARCH ARTICLE

INFANCY THE OFFICIAL JOURNAL OF THE INTERNATIONAL CONGRESS OF INFANT STUDIES WILEY

# Cognitive control in infancy: Attentional predictors using a tablet-based measure

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**Funding information**
UK Research and Innovation, Grant/Award Number: ES/V016601/1; MR/S018425/1; Bill and Melinda Gates Foundation, Grant/Award Number: OPP1061089; OPP1127625; Medical Research Council and Department for International Development, Grant/Award Number: MC-A760-5QX00; Wellcome Trust, Grant/Award Number: 220225/Z/20/Z

**Abstract**

Cognitive control is a predictor of later-life outcomes and may underpin higher order executive processes. The present study examines the development of early cognitive control during the first 24-month. We evaluated a tablet-based assessment of cognitive control among infants aged 18- and 24-month. We also examined concurrent and longitudinal associations between attentional disengagement, general cognitive skills and cognitive control. Participants ($N$ = 60, 30 female) completed the tablet-task at 18- and 24-month of age. Attentional disengagement and general cognitive

The editor of this article is Gavin Bremner.
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development were assessed at 5-, 8-, 12-, 18- and 24-month using an eye-tracking measure and the Mullen Scales of Early Learning (MSEL), respectively. The cognitive control task demonstrated good internal consistency, sensitivity to age-related change in performance and stable individual differences. No associations were found between infant cognitive control and MSEL scores longitudinally or concurrently. The eye-tracking task revealed that *slower* attentional disengagement at 8-month, but *faster* disengagement at 18-month, predicted higher cognitive control scores at 24-month. This task may represent a useful tool for measuring emergent cognitive control. The multifaceted relationship between attention and infant cognitive control suggests that the rapid development of the attentional system in infancy results in distinct attentional skills, at different ages, being relevant for cognitive control development.

## 1 | INTRODUCTION

Cognitive processes essential for achieving goals, adapting to the environment, and regulating behaviors have been identified as crucial for child development (Carlson, 2005; Thompson & Steinbeis, 2020). Emerging cognitive control, over time, gives rise to higher order cognitive and executive function (EF) abilities. EF has been conceptualized as three interrelated components: working memory (WM), inhibitory control (IC) and cognitive flexibility (CF). WM is the ability to retain and manipulate information. IC is the ability to control attention, behavior, and emotions. CF includes the ability to change perspectives and understand rule changes (Diamond, 2013; Garon et al., 2008; Miyake et al., 2000). More recent work has proposed a common EF factor which unites these three components and suggests that inhibitory abilities may be foundational to all (Friedman & Miyake, 2017). Developmentally, some evidence on preschoolers highlights that, while EF may be regarded as a more unitary construct in the early preschool years, it then continues to differentiate with more separable components being observable during middle childhood (Garon et al., 2008). There is growing interest in the development of EFs in early childhood, as these skills have been found to predict social, emotional, and academic outcomes both cross-sectionally and longitudinally. However, due to methodological and conceptual constraints, there remains a paucity of research that examines the emergence of early cognitive control and executive processes in young, pre-verbal children, and, consequently, potential longitudinal associations between early predictors and EF development remain relatively unexplored.

The present study evaluates the use of a novel, tablet-based assessment of emergent cognitive control at 18- and 24-month, drawing on a range of tasks that may underpin more complex EFs later on (BabyScreen app, Twomey et al., 2021; Twomey et al., 2018). Furthermore, we explore the associations between early cognitive control skills at 18- and 24-month with measures of attentional flexibility (measured by an eye-tracking task of attentional disengagement) and overall cognitive skills (measured by a behavioral assessment of language, motor, and perceptual skills), assessed at multiple intervals during the first 24-month of life. The findings from this study will, therefore, contribute to a better understanding of the early attentional underpinnings contributing to emerging cognitive control, as well as provide the basis of follow-on longitudinal work examining links with more complex EFs during the preschool years and beyond.

## 1.1 | Emergence of infant cognitive control

Garon et al. (2008) proposed a hierarchical model of EF development based on the three-factor structure (WM, IC, CF) conceptualized in adults, with basic cognitive skills developing before 3-years of age, which are later integrated to form EFs. The model suggests that attentional abilities are foundational to all EFs and thus develop first, during the first 6-month of life, and continuously thereafter. WM subsequently develops at around 6-month, IC at 8-month and CF at 12-month. However, as with theories stemming from literature on adults, there is also some evidence to suggest that EF abilities may comprise a more unitary structure, so the exact timing of component development is uncertain (Fiske & Holmboe, 2019). In line with this proposed developmental timeline, associations between emergent cognitive skills, cognitive control, and executive processes have been reported both concurrently and longitudinally (Holmboe et al., 2018; Stephens et al., 2018). For example, Holmboe et al. (2018) found concurrent associations between general cognitive skills and IC at 9-month, using both a behavioral assessment of IC (the A-not-B task) and an eye-tracking measure (the Freeze Frame task). Furthermore, cognitive ability at 24-month has been found to be predictive of EFs at 6-year (Stephens et al., 2018). Despite these promising results, it is often challenging to measure cognitive skills early in infancy using behavioral, examiner-led assessments (Brian et al., 2014; Yaari et al., 2018), which has resulted in a general paucity in research examining EF development during the first months of life.

Furthermore, while attentional mechanisms in early infancy are recognized as important predictors subsequent cognitive control and EF processes, the nature of this relationship is complex and may change during the first 2-years (Hendry et al., 2019). Attentional abilities are described as comprising of alerting, orienting and executive networks (Posner & Rothbart, 2006). The *orienting network*, which promotes fast shifting of attention, begins to develop between 3- to 6-months and is thought to be important for EFs in early infancy. This is supported by Cuevas and Bell (2014), who found that infants who exhibited shorter looking durations (which was posited to reflect faster disengagement) in a behavioral task at 5-months had more advanced EFs at 24-, 36-, and 48-months than those with longer looking times. Using the same behavioral assessment, Devine et al. (2019) reported that shorter looking times at 4-months were a stronger predictor of EFs at 14-months than parent-rated temperament. Taken together, this work supports the idea that attentional flexibility (measured through faster attentional disengagement) in the early part of the first year of life predicts better EF skills later in infancy/childhood.

As infants mature, a proposed shift occurs, whereby the *executive network* (responsible for sustained attention and resolving conflict) becomes increasingly relevant for cognitive development (Geeraerts et al., 2019; Posner et al., 2012). Kannass et al. (2006) suggest that endogenous control of attention, which is a foundational component of the executive network, starts to develop around 9-months. Thus, beginning at the onset of the second year of life, the ability to sustain attention may become more important than attentional flexibility for emergent EF skills. Indeed, sustained attention at 12-months has been reported to be predictive of EFs (measured using the A-not-B task) at 24-months (Johansson et al., 2015). On the other hand, Nakagawa and Sukigara (2013) found that, at 12-months of age, slower disengagement times predicted less advanced concurrent self-regulation capabilities. However, longitudinally, slower disengagement at 12-months predicted more advanced effortful control at 18- and 24-months of age. This suggests that sustained attention may become relevant for cognitive control and executive processing skills later than previously thought, between 12- to 18-months. Taken together, prior research provides evidence to support the role of both the orienting network in early infancy and a shift to reliance on the executive network between 9- and 18-months of age in EF development. However, there is a scarcity in longitudinal research, spanning multiple time points during the first 2-years, that examines how the progression of attentional skills impacts EF development. Thus, it is difficult to establish whether reports of both sustained and flexible attention predicting EF skills truly reflect a shift in the attentional networks or if this is an artifact of the diverse experimental methods used to assess both attention and EFs. Furthermore, longitudinal research incorporating assessments at 7- to 11-months, an age largely overlooked in prior research, would be helpful in establishing a clearer frame in the timing of shifts in the attentional skills relevant for EFs.

## 1.2 | Measuring early cognitive and executive control

While theoretical models propose that early predictors of EFs start to develop during the first 3-year of life (Garon et al., 2008), most research on the early development of EFs focuses on older children (Best & Miller, 2010; Garon et al., 2008). This may be because infants' limited motor and language skills restrict their ability to complete traditional EF tasks (Hendry et al., 2016). Given that neural networks exhibit their highest plasticity during the first 24-months, it is crucial to be able to measure the development of EFs during infancy, as this could support the development of more effective and longer-lasting interventions for delayed EF development (Bornstein, 2014; Fiske & Holmboe, 2019; Wass et al., 2011). Common methods of assessing EFs in infancy include parental report, behavioral, and eye-tracking tasks, as well as neuroimaging tasks.

Tasks aimed at understanding early cognitive control and executive processes oftentimes focus on processes such as (1) multi-location object retrieval tasks, (2) simple inhibition paradigms, and (3) rule switching paradigms. While such tasks represent early correlates of emergent cognitive control and EFs, they have provided important insight. For example, seminal work on object permanence by Adele Diamond's group using the A-not-B task (Diamond et al., 1997; Diamond, 1985) highlighted that the task draws on WM (with infants becoming progressively better at tolerating longer delays and a larger number of hiding locations), IC (even when reward is visible, infants will "search" in wrong location), and updating (indexed by perseveration). Another relevant line of research stems from developmental neuroscience, which has shown that the developmental milestone of infants achieving object permanence is mirrored by increased activation in prefrontal cortex activity (Baird et al., 2002).

Increasingly, improved technology makes it feasible to translate tasks such as object-retrieval tasks to tablet-based modes of delivery, which provides some advantages, including the reduction of time-consuming manual coding, biased interpretation, and expensive equipment (Frank et al., 2016; Hendry et al., 2016). Tablet based tasks have shown promise for reliable measurement of the precursors of EFs in infancy. They can collect multiple types of variables, including accuracy in item completion, touch patterns and reaction times, and are thought to be engaging and relatively inexpensive and so can be used to increase the scale of research (Bhavnani et al., 2019; Frank et al., 2016; Friend & Keplinger, 2003).

Tablet tasks have been used extensively to measure early cognitive control and executive processes in children over 2-years (Pitchford & Outhwaite, 2016; Semmelmann et al., 2016; Willoughby et al., 2019) but emerging evidence shows promise for their use among younger infants. The Early Childhood Inhibitory Touchscreen Task developed by Holmboe et al. (2021) is thought to be a valid measure of IC showing good 1-week test re-test reliability in infants aged 10-month, association with performance on the behavioral A-not-B task at 16-month, and evidence of some developmental improvement between these time points (Hendry et al., 2022). Fiske et al. (2022) also concluded that the task is a suitable measure of IC in infants. Lo et al. (2021) demonstrated that 18- to 20-month-olds could meaningfully engage with a tablet task measuring reading comprehension. Furthermore, Frank et al. (2016) found that, compared to eye-tracking and storybook paradigms, their tablet task had higher completion rates for 1- and 2-year-olds. However, further research is needed to establish whether tablet tasks can be used to measure global cognitive control abilities in infancy.

## 1.3 | The present study

Data used for this study were collected as part of the Brain Imaging for Global Health project (BRIGHT; globalfnirs.org/the-bright-project), a longitudinal study examining infant development from birth to preschool age. Our first aim was to evaluate the utility of a novel tablet task, the BabyScreen app (Hello Games Ltd, UK), in measuring emerging cognitive control in infancy. The BabyScreen was developed for use with children aged 12–36 months and is based on infant measures of cognitive control and emergent EFs (Twomey et al., 2018). For example, the BabyScreen captures responses on hidden object retrieval tasks (an early measure of WM (Diamond et al., 1985, 1995; Katus et al., 2023; Marcovitch & Zelazo, 2009) and the picture deletion tasks which measure inhibition and selective attention (Twomey et al., 2018). The BabyScreen score is a combined measure of performance on all tasks and so is considered a measure of global emerging cognitive control abilities. While emerging and developing EFs have been considered to have a three-factor structure, there is some evidence to suggest that EFs, particularly emerging EFs, may have a more unitary structure than originally conceptualized (Fiske & Holmboe, 2019), which is reflected in the BabyScreen's outcome measure, where tasks are used to obtain an overall cognitive control index.

Initial validation work suggests that the BabyScreen is sensitive to age-related changes in cognitive ability, for example, children aged 30–36 months completed a greater number of trials and were faster in completing the more complex tasks than those aged 24–29 months (Twomey et al., 2018). Furthermore, Twomey et al. (2021) demonstrated a positive association between performance on the BabyScreen and general cognitive skills, measured by the Bayley Scales of

Infant and Toddler Development, among infants aged 18- to 24 months. Casey et al. (2023) also found a moderate positive association between Bayley Scales scores and performance on the BabyScreen, and that low Babyscreen scores could predict scores indicative of cognitive delay on the Bayley Scales. This study aims to extend these findings by examining the development of BabyScreen performance with a longitudinal design and examining associations with both global cognitive skills and attentional disengagement, measured at multiple intervals during the first 2-years of life (at 5-, 8-, 12-, 18- and 24-months). We expect to reproduce and extend Twomey et al. (2018) findings, whereby we anticipate that infants will have better performance on the BabyScreen at 24-months than at 18-months, and that task performance at the two time points will be correlated. Secondly, given that prior work has found an association between global cognitive skills and emergent cognitive control (e.g., Holmboe et al., 2018; Twomey et al., 2018), we posit that there will be both concurrent and longitudinal positive associations between BabyScreen scores and measures of general cognitive skills. Regarding possible associations between early cognitive control and attentional markers, we expect that, initially, *faster* disengagement at 5-months will predict higher scores on the BabyScreen task at 18- and 24-months. However, coinciding with the shift in salience from the orienting to the executive network in supporting the development of attentional control and executive processes, we also expect that the direction of this association will change around 12-months, when *slower* disengagement thereafter will predict higher BabyScreen scores. Finally, we do not make a specific hypothesis about the association at 8-months given the scarcity of literature on this age point.

## 2 | METHODS

### 2.1 | Participants

This study uses data from the UK cohort within the BRIGHT Project. While the study has been conducted in both the UK and The Gambia, the BabyScreen assessments described in the present study were only administered in the UK (see Lloyd-Fox et al., 2023, for further discussion about feasibility work within The Gambian cohort).

Once per week during the recruitment period, all families attending their 32–36-week antenatal visit at the Rosie Hospital, Cambridge University Hospitals, were provided with study information. Families were recruited if they provided informed consent and had healthy pregnancies. Infants were only included if they were born between 37- and 42-weeks' gestation, were a singleton, had no diagnosis of any major medical or neurological difficulties at birth and had a birth weight of over 2.5 kg. Sixty-two infants (50% female) were recruited. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the National Research Ethics Service Committee East of England (REC reference 13/EE/0200).

Participants were invited to 8 scheduled visits from late pregnancy to 24-months postpartum. The visits included eye-tracking and behavioral assessments (for full protocol, see Lloyd-Fox et al., 2023). Figure 1 details the specific ages at each study visit, the number of participants that attended the visit, and reasons for participant withdrawal. The current

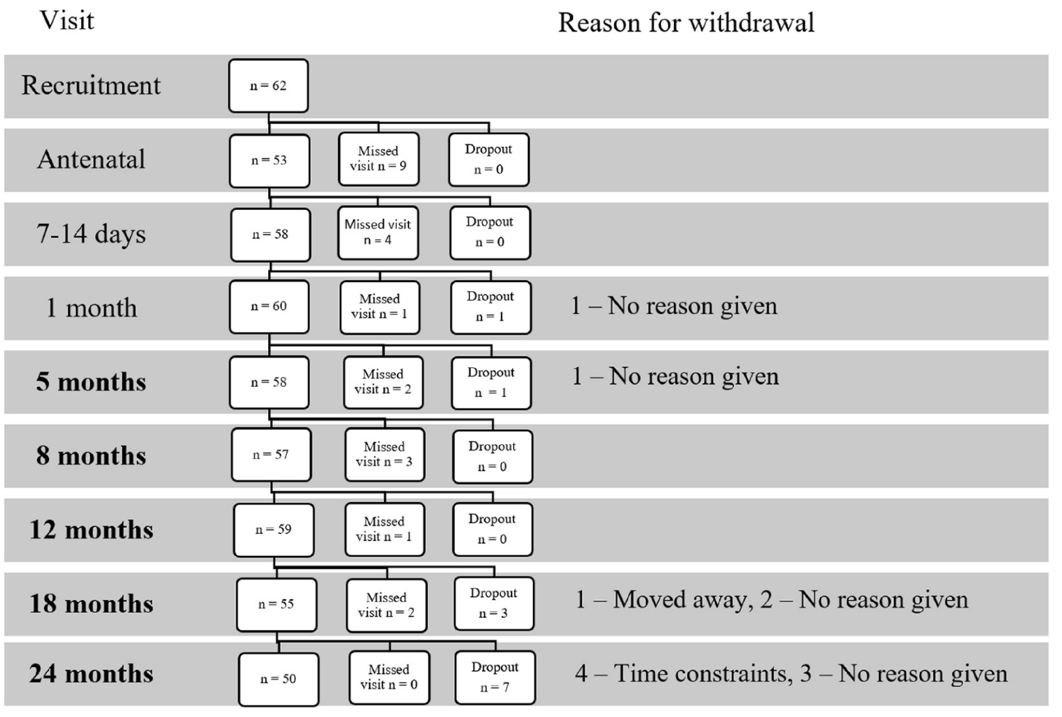



**FIGURE 1** Number of participants at each visit and reasons for withdrawal. Those in bold are the age points used in the current analysis.

analyses use data from the 5-, 8-, 12-, 18- and 24-month visits. Two participants withdrew before the 5-month visit so the sample examined here comprises 60 participants (50% female).

## 2.2 | Demographic data

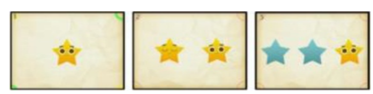
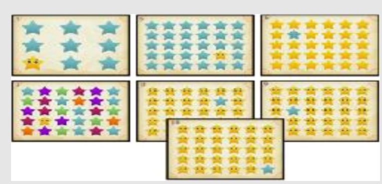
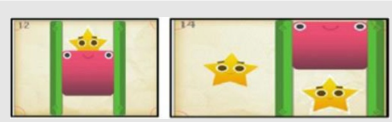
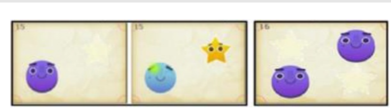
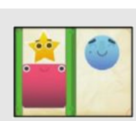
Demographic data were collected at the initial antenatal visit, and at 8- and at 18-month post-partum visits by questionnaire. For the current analysis, data from the 18-month visit were used as this was closest in time with the administration of the BabyScreen measures. Given prior research, which showed that both maternal education and family income are associated with children's neurocognitive development and early cognitive control in particular (Hackman et al., 2015; Lawson et al., 2014), information on these demographic characteristics were used in analyses. *Household income* was assessed via a single question asking parents to choose a category that best described their annual household income (<£20,000; £20,000–29,000; £30,000–39,000; £40,000–59,999; £60,000–79,000; £80,000–99,999; £100,000–149,999; >£149,999). They were also given an option not to respond. *Maternal education* was also assessed using a single question asking mothers to indicate their highest level of education (Primary; Secondary; Tertiary graduate; Tertiary postgraduate), also with an option not to respond. Finally, data were collected about *participant racial background* by asking parents to indicate both the mother's and father's ethnicity from a set of five options (White, Asian, Black, mixed race and other/don't know). Infant race was ascertained from parents' race and, where parents were from different racial groups, the infant was identified as being biracial or mixed race.

## 2.3 | Cognitive control measures

The BabyScreen software application version 1.5 (Hello Games Ltd, UK) was administered at 18- and 24-month to measure emerging cognitive control. The task is an 18-item tool that was developed for use with infants aged 12–36 months. It provides a unitary measure of skills but is comprised of items that elicit specific components of emerging EFs, including WM and selective attention, and is based on widely used assessments of EF for older children (see Table 1, Twomey et al., 2018).

Items involve performing a set of problem-solving tasks, which increase in difficulty as the task progresses. The task was presented on an iPad (5th generation, 9.7-inch screen) set to full

**TABLE 1** Overview of BabyScreen trials.

| Task numbers | Construct measured | Brief description | Trial screenshots |
|---|---|---|---|
| 1–3 | Training items | Infants are required to press the gold star with a face to pass to the next trial. Teaches infants that the gold star is the target |  |
| 4–9, 18 | Selective attention/ response inhibition | Infants must touch the target star while inhibiting responses to distractor stars. The target changes with each trial and difficulty is increased by increasing the number of distractors |  |
| 10, 11, 13 | Working memory | Infants watch the target star be covered by one of two cups. Infants must interact with the cup to uncover the target star |  |
| 12, 14 | Hidden object retrieval | Infants watch the target star be covered by a box. Infants must interact with the box to uncover the target star. Infants must do this twice on trial 14 |  |
| 15, 16 | Object permanence | Infants must press a button to make the target star appear and simultaneously press the star to make it disappear. Infants must do this twice on trial 16 |  |
| 17 | Learning | This trial requires a combination of techniques used in the hidden object retrieval and object permanence trials |  |

*Note*: The table, pictures and *construct measured* labels are adapted from Twomey et al. (2018).

brightness, 70% of the maximum volume and affixed horizontally to a table. Participants either sat on their parent's lap or stood at the table. Prior to starting the BabyScreen, participants were familiarized with the iPad by playing a game where they could draw on the screen. The BabyScreen task started with three training items, which were followed by the test trials. Participants were given two attempts to solve each trial. They were initially given an opportunity to solve the task independently (first attempt), without any instructions or support. If they did not respond correctly within 20s at 18 months or 30s at 24 months, the experimenter was prompted to give a demonstration. After the demonstration, participants were given another attempt to complete the trial (second attempt). Images of balloons and music were presented as a reward for trial completion. If the trial was not completed correctly on either the first or second attempt, it was skipped. The task was terminated either when infants completed all trials or when they failed to complete three consecutive trials. Experimenters made notes during each trial to indicate if anything affected infant performance (e.g., inattentiveness or fussiness). Parents were also asked to rate their infant's previous touchscreen use on the following scale: never, occasionally, 2–3 times per week, or daily.

The BabyScreen generates two variables for each trial attempt: accuracy (whether the trial was completed successfully) and reaction time (RT; speed of trial completion for successful trials). A feasibility study suggested that the total number of trials completed without demonstration (first attempts) was best able to capture age differences in performance (Twomey et al., 2021). Therefore, the total number of items completed without demonstration (hereafter "BabyScreen score") was used for primary analyses. The mean RT for trials on the first attempt was also computed and used in analyses.

## 2.4 | General cognitive ability

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) are a battery of assessments designed to measure cognitive and gross motor abilities from birth to 68 months. In this study, the MSEL was administered at 5-, 8-, 12-, 18- and 24-months of age. Cognitive abilities are measured by four subscales: fine motor, receptive language, expressive language, and visual reception. The fifth subscale measures gross motor abilities. Each scale is assessed through a series of interactive tasks presented in order of increasing difficulty. Examiners rated whether participants successfully completed each task. Total scores for each subscale were computed and converted to age-normed t-scores based on a US sample ($M$ = 50, *standard deviation (SD)* = 10; Mullen, 1995). The Early Learning Composite ($M$ = 100, $SD$ = 15) was subsequently derived from all cognitive t-scores and was used as a measure of overall cognitive ability. The MSEL Early Learning Composite is used in analyses for the present study.

## 2.5 | Attentional disengagement

The gap-overlap task is designed to measure attentional disengagement through testing infants' ability to orient to stimuli in their peripheral vision. The task was conducted as part of a battery of eye-tracking tasks at 5-, 8-, 12-, 18- and 24-months. The procedure is described by Glennon et al. (2020) and Jones et al. (2019). Every trial started with the presentation of a central stimulus (image of analog clock), which was accompanied by an alerting sound. This remained on the screen at 3 Hz between 3 and 5 cm (2.86°–4.77°) until participant fixated on the central stimulus. Upon fixation, the central stimulus began to rotate at 500° per second for a random interstimulus interval, ranging between 500 and 700 ms and then remained on screen static for 200 ms. The current study used attentional disengagement based on the baseline condition from the gap-overlap task, in which a peripheral stimulus (a cartoon cloud) was presented on either the left or right side of screen directly following offset of the central stimulus presentation. The peripheral stimulus was presented 3 cm (2.86°) from the edge, accompanied by an alerting sound. It was rotated at 500° per second until participant fixated on it. A reward stimulus was presented for 1000 ms (cartoon animal accompanied by a sound) when participant successfully fixated on the peripheral stimulus. Trials were presented in blocks of 12, all stimuli were presented at 3 cm by 3 cm (2.86° by 2.86°). We calculated saccadic reaction time per trial for the attention shift of central stimulus to peripheral stimulus, relative to the onset of PS presentation.

Eye movements were recorded using a Tobii TX300 eye-tracker (Tobii Technology, Stockholm, Sweden) with 300 Hz refresh rate set to a sampling rate of 60 Hz. Visual stimuli were presented on a 23-inch monitor. Infants faced the screen while sitting on their parent's lap 60 cm from the screen. Once calibrated to infants' eye movements, the task started, and infants' eye movements were recorded. The session was paused if the infant fussed out and only resumed if possible. Data were subsequently analyzed offline.

Participant data were removed if they had fewer than 6 valid trials in the target condition. Trials were considered valid if (1) gaze fell on the central stimulus; (2) there were no periods of missing data longer than 200 ms during central stimulus presentation; (3) there was at least one period of gaze on the central stimulus; (4) there were no periods of missing data longer than 100 ms during the peripheral period; (5) SRTs ranged between 150 and 1200 ms; (6) gaze was not on the opposite side of screen to the peripheral stimulus; (7) gaze was not within the peripheral stimulus area of interest during the period after engagement with the central stimulus but before peripheral stimulus onset. **Attentional disengagement** was calculated as the outcome variable by subtracting SRTs in the baseline condition from SRTs in the overlap condition.

## 2.6 | Statistical analyses

Analyses were conducted in R Studio (R Core Team, 2020). Outlier identification was conducted by the boxplot method using the rstatix package (Kassambara, 2020). Outliers were removed if they were extreme outliers (based on the interquartile range) and experimenter notes suggested that the data quality was poor (e.g., participant was upset or highly inattentive during the task indicating that the results were not representative of the infant's ability and should not be used for analysis). Analyses including the outlying infants can be found in the Supporting Information S1. Descriptive statistics (Mean, Standard Deviation) were computed for all variables.

Repeated-measures ANOVAs were conducted to assess age-related change in MSEL and gap-overlap scores between 5- and 24-month. To limit the spurious results attributable to multiple comparisons, we only tested post-hoc comparisons where ANOVA or regression models indicated group-level differences. If the ANOVAs showed significant change with age, post-hoc tests using Bonferroni correction were used to identify which age points significantly differed from each other on each task.

ANOVA assumptions were tested via Shapiro-Wilk tests, and Levene's tests. Where homoscedasticity was violated, a Brown-Forsythe correction was applied. Mauchly's test was used to test for sphericity.

#### 2.6.1 | Evaluation of the BabyScreen

To investigate whether demographic factors influenced BabyScreen scores, one-way between-subjects ANOVAs were conducted. These determined whether there were significant differences between the BabyScreen scores of infants with different levels of each demographic variable (sex, annual household income, maternal education, and previous touchscreen use).

To determine whether the BabyScreen could detect changes in scores between 18- and 24-month, a paired Wilcoxon-signed rank test was conducted. Effect sizes (*r*) were calculated by $Z/\sqrt{N}$ (Rosenthal, 1991, as cited in Field et al., 2012). To ensure that the change in RT allowance between visits (20s at 18-months and 30s at 24-months) did not affect differences in BabyScreen scores between visits, a general linear model (GLM) was constructed with BabyScreen score as the dependent variable, age point as a fixed effect, and mean RT as a random effect.

Pearson correlation tests were used to determine whether there was an association between BabyScreen score and mean RT, and to determine whether participants' scores were correlated between 18- and 24- months. Cronbach's alpha was used to assess the internal consistency of BabyScreen scores. All items on the BabyScreen were included when calculating internal consistency score as they were hypothesized to contribute to the same underlying construct.

#### 2.6.2 | Associations between performance on the BabyScreen, cognitive ability and attentional disengagement times

To investigate the concurrent and longitudinal relationships between MSEL Early Learning Composite scores and gap-overlap disengagement times and BabyScreen scores, multivariate multiple regression models were constructed. This is an extension of multiple regression, in which one can measure the association between multiple dependant variables with a single set of predictors and covariates, accounting for residual correlations (Muñoz-Rocha et al., 2018). Five models were run using data from each study visit separately (5-, 8-, 12-, 18- and 24-months). BabyScreen scores at 18- and 24-months were included as the dependant variables, and MSEL Early Learning Composite and gap-overlap disengagement scores were included as predictors. For the model with predictors at 24-months, a linear regression was run including only 24-month BabyScreen scores as the dependent variable. Given that there were no significant associations between sex or any of the demographic/family characteristics and BabyScreen performance (see Results for summary), these were not controlled for in the regression models.

## 3 | RESULTS

### 3.1 | Participant demographics

Table 2 summarizes participant age and sex ratio at each study visit relevant to present analyses (5–24 months). There were no significant differences in sex distribution at any of the visits.

**TABLE 2** Sample size, descriptive statistics for age (days) and sex ratio at each visit.

| Visit | *N* | Mean (SD) age in months | Sex ratio (M:F) |
|---|---|---|---|
| 5-month | 58 | 5.13 (0.21) | 29:29 |
| 8-month | 57 | 8.28 (0.33) | 28:29 |
| 12-month | 59 | 12.35 (0.41) | 29:30 |
| 18-month | 55 | 18.32 (0.49) | 27:28 |
| 24-month | 50 | 24.23 (0.52) | 23:27 |

Table 3 summarizes participant and family demographic characteristics, measured at the 18-month visit. Of the 60 participants, all families reported an annual household income above £30,000. Furthermore, 78% of the infants' mothers had higher education qualifications, with 47% having postgraduate degrees. Most participants were white (93%) and there were no families where mothers and fathers were from different racial/ethnic backgrounds.

## 3.2 | Descriptive statistics

Table 4 summarizes performance on the experimental tasks (BabyScreen scores, MSEL Early Learning Composite, gap-overlap disengagement), after removal of extreme outliers for each task.

A significant effect of age point was observed with the MSEL Early Learning Composite scores, $F(4, 48) = 9.92$, $p < 0.001$, $\eta^2p = 0.45$. Scores at 24-month were significantly higher than at all other visits, but all other comparisons were non-significant (see Figure 2). Disengagement times during the gap-overlap task decreased across study visits, $F(2,80) = 17.56$, $p < 0.001$, $\eta^2p = 0.47$, but the only significant difference between consecutive study visits was between 8- and 12-month (see Figure 3).

## 3.3 | Effect of demographic factors on BabyScreen scores

There was no significant effect of sex on BabyScreen performance at 18-months $F(1, 34) = 0.18$, $p = 0.68$, $\eta^2 = 0.01$) or 24-months $F(1, 30) = 0.02$, $p = 0.90$, $\eta^2 = 0.00$). Likewise, there was no effect of annual household income at either 18-months ($F(5, 25) = 1.32$, $p = 0.29$, $\eta^2 = 0.02$) or 24-months ($F(4, 22) = 0.18$, $p = 0.94$, $\eta^2 = 0.03$). There was also no impact of maternal education at either 18-months $F(2, 28) = 2.10$, $p = 0.14$, $\eta^2 = 0.14$) or 24-months $F(3, 26) = 2.34$, $p = 0.10$, $\eta^2 = 0.21$). Finally prior touch screen use did not impact BabyScreen performance at either 18-months $F(3, 13) = 1.27$, $p = 0.33$, $\eta^2 = 0.07$) or 24-months $F(3, 28) = 0.25$, $p = 0.86$ $\eta^2 = 0.03$).

## 3.4 | Change in BabyScreen scores with age and associations with RT

BabyScreen scores were significantly higher at 24-month than at 18-month, $W(19) = 18.5$, $p = 0.006$, with a large effect size, $r = 0.658$ (see Figure 4). Additionally, there was a significant correlation between BabyScreen scores at 18- and 24-months, $r(17) = 0.50$, $p = 0.03$.

**TABLE 3** Infant and family demographic characteristics at 18-month and participant prior touchscreen use.

| Demographic characteristic | Frequency of rating (% of sample) | |
|---|---|---|
| Annual household income (£) | | |
| <20,000 | 0 (0%) | |
| 20,000–29,000 | 0 (0%) | |
| 30,000–39,999 | 4 (7%) | |
| 40,000–59,999 | 13 (22%) | |
| 60,000–79,999 | 9 (15%) | |
| 80,000–99,999 | 13 (22%) | |
| 100,000–149,999 | 6 (10%) | |
| Do not wish to answer | 3 (5%) | |
| Missing data | 12 (20%) | |
| **Parental education level** | **Mothers** | |
| Secondary | 2 (3%) | |
| Tertiary | 1 (2%) | |
| Undergraduate | 21 (35%) | |
| Postgraduate | 27 (45%) | |
| Missing data | 9 (15%) | |
| **Parental race** | **Mothers** | **Fathers** |
| White | 56 (93%) | 56 (93%) |
| Asian | 2 (3%) | 2 (3%) |
| Black | 1 (1%) | 1 (1%) |
| Mixed | 0 (0%) | 0 (0%) |
| Other/don't know | 2 (3%) | 2 (3%) |
| **Previous touchscreen use** | **18 months** | **24 months** |
| Never | 6 (10%) | 4 (7%) |
| Occasionally | 21 (35%) | 15 (25%) |
| 2–3 times per week | 3 (5%) | 9 (15%) |
| Daily | 8 (13%) | 6 (10%) |
| Missing data | 22 (37%) | 26 (43%) |

There were significant negative associations between BabyScreen scores (number of successfully completed items) and RT to complete task at both visits ($r(34) = -0.39$, $p = 0.02$ at 18-month; $r(31) = -0.74$, $p < 0.01$ at 24-month), suggesting that those who scored higher on the BabyScreen also completed trials faster. In spite of this, a GLM revealed that adding RT as a random effect did not impact on the effect of visit on BabyScreen performance, $F(1,67) = 5.00$,

**TABLE 4** Descriptive statistics for each experimental task and number of participants that completed the task at each study visit.

| Task (variable [unit]) | Visit | *N* | *M* (*SD*) |
|---|---|---|---|
| BabyScreen total score | 18-month | 38 | 12.17 (2.63) |
| | 24-month | 34 | 13.64 (2.83) |
| BabyScreen (average RT [ms]) | 18-month | 38 | 13,661.99 (2950.78) |
| | 24-month | 34 | 15,978.74 (3956.00) |
| MSEL (early learning composite score) | 5-month | 56 | 93.80 (11.61) |
| | 8-month | 57 | 94.17 (12.70) |
| | 12-month | 54 | 91.12 (14.57) |
| | 18-month | 55 | 101.86 (16.34) |
| | 24-month | 49 | 113.10 (14.21) |
| Gap-overlap (average disengagement (ms)) | 5-month | 56 | 163.42 (77.03) |
| | 8-month | 55 | 129.38 (68.85) |
| | 12-month | 49 | 93.31 (50.85) |
| | 18-month | 47 | 75.50 (52.04) |
| | 24-month | 46 | 59.09 (43.13) |

*Note*: Outliers were removed due to low (but above cut off) number of valid trials, as well as experimenter notes indicating the infant only intermittently focused on the screen. Analyses with $n = 3$ outliers included can be found in the supplementary material.

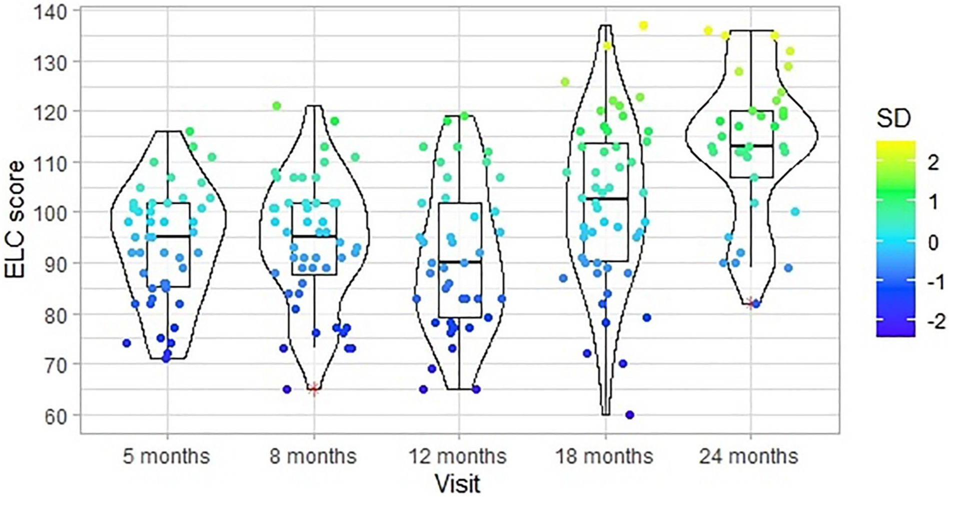



**FIGURE 2** Distribution of MSEL Early Learning Composite scores at the 5-, 8-, 12-, 18- and 24-month visits. The middle line represents the median, upper bound quartile 3 and lower bound quartile 1 of the scores. Violin plots show the distribution of scores. Colored points represent individual MSEL scores from infants and are colored by standard deviation from the mean score for the relevant visit.

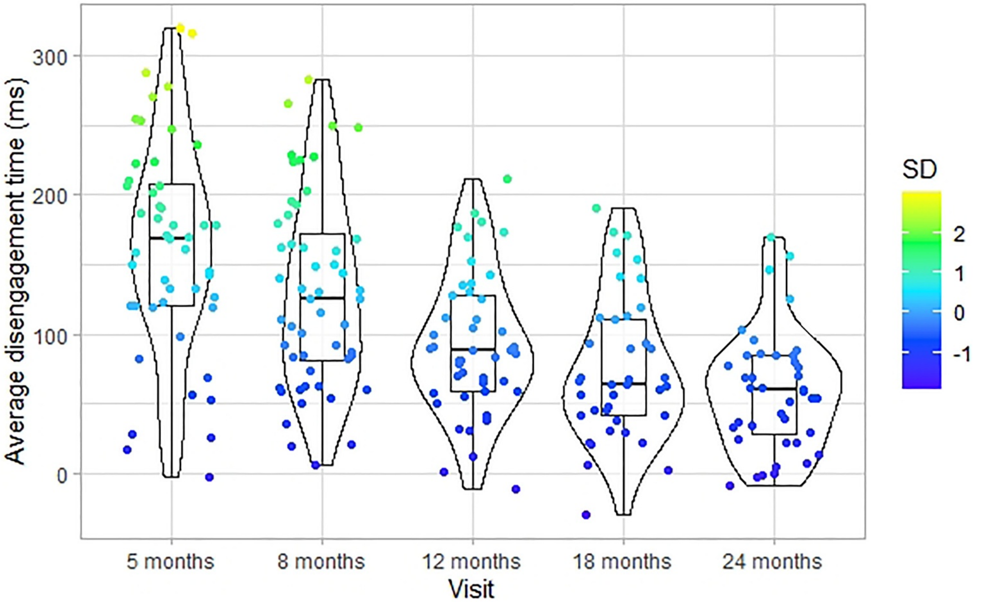



**FIGURE 3** Distribution of disengagement times as measured by the Gap-Overlap task at the 5-, 8-, 12-, 18- and 24-month visits. Disengagement times presented in box plots where the middle line represents the median, upper bound quartile 3 and lower bound quartile 1 of the scores. Violin plots show the distribution of scores. Points represent individual disengagement times from infants and are colored by standard deviation from the mean score for the relevant visit.

$p$ = .03. This suggests that differences in RT, and thus the increased time allowance given to complete trials at 24-months, did not account for increases in BabyScreen scores between 18- and 24-months. Finally, the BabyScreen showed good internal consistency at both 18- ($\alpha = 0.83$) and 24-months ($\alpha = 0.86$).

## 3.5 | Concurrent and longitudinal relationships between BabyScreen scores, cognitive skills and attentional disengagement

Table 5 summarizes the multivariate multiple regressions examining associations between BabyScreen performance, MSEL Early Learning Composite and gap-overlap disengagement scores at each visit. MSEL scores had no longitudinal or concurrent associations with BabyScreen scores at either 18- or 24 months. In contrast, gap-overlap disengagement times at 8 months were positively associated with BabyScreen scores at 24 months, while gap-overlap disengagement times at 18-months were negatively associated with BabyScreen scores at 24 months. This suggests that slower disengagement times at 8-months were associated with higher BabyScreen scores at 24-months, whereas faster disengagement times at 18-month were associated with higher BabyScreen scores at 24-months. No further associations were found between gap-overlap disengagement times and BabyScreen scores. These associations are summarized in Figures 5 and 6.

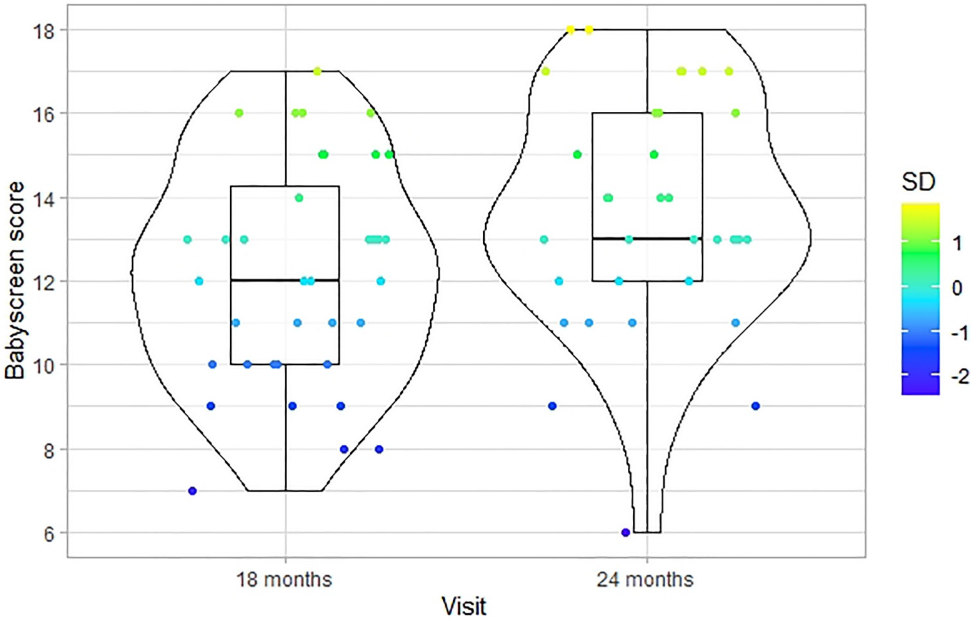



**FIGURE 4** Distribution of BabyScreen scores at the 18- and 24-month visits. BabyScreen scores at 18 months (left) and 24 months (right) in box plots where the middle line represents the median, upper bound quartile 3 and lower bound quartile 1 of the scores. Violin plots show the distribution of scores. Points represent individual BabyScreen scores from infants and are colored by standard deviation from the mean score for the relevant visit.

# 4 | DISCUSSION

This study evaluated the utility of the BabyScreen task, a novel, tablet-based task in assessing emerging cognitive control abilities among infants in the second year of life (aged 18- and 24-months). Longitudinal and concurrent associations between early cognitive control in the second year and general cognitive and attentional markers earlier in infancy were also measured. The BabyScreen demonstrated good internal consistency and was sensitive to age related change, showing stable individual differences in scores between 18- and 24-months. Associations were also found between BabyScreen scores at 24-months and attentional disengagement at both 8- and 18-months. However, these associations were contrary to expectations—*slower* disengagement times at 8-months predicted better cognitive control scores at 24-months, while *faster* disengagement at 18-months was associated with increased performance at 24-months. There were no further associations between speed of attentional disengagement and cognitive control measures at either age point. Furthermore, there were no significant concurrent or longitudinal associations between global cognitive skills (measured by the MSEL) and cognitive control.

## 4.1 | Evaluation of the BabyScreen task in assessing cognitive control in the second year of life

The BabyScreen task demonstrated good performance across several metrics, suggesting that it has promise as a tool to assess cognitive control abilities among infants as young as 18-month of

**TABLE 5** Summary of multivariate multiple regression predicting BabyScreen scores at 18- and 24-months from MSEL Early Learning Composite scores and gap-overlap disengagement times at 5-, 8-, 12-, 18- and 24-months.

| | **Outcomes** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **BabyScreen score 18-month** | | | | **BabyScreen score 24-month** | | | |
| **Predictors** | ***B*** | ***SE*** | ***t*** | ***p*** | ***B*** | ***SE*** | ***t*** | ***p*** |
| 5 months | | | | | | | | |
| MSEL early learning composite | 0.08 | 0.08 | 1.09 | 0.30 | 0.09 | 0.08 | 1.15 | 0.28 |
| Gap-overlap disengagement | 0.01 | 0.01 | 0.80 | 0.44 | 0.00 | 0.01 | 0.45 | 0.67 |
| 8 months | | | | | | | | |
| MSEL early learning composite | 0.07 | 0.08 | 0.82 | 0.43 | 0.07 | 0.05 | 1.50 | 0.17 |
| Gap-overlap disengagement | 0.00 | 0.01 | 0.20 | 0.85 | **0.03** | **0.01** | **3.50** | **0.01**[a] |
| 12 months | | | | | | | | |
| MSEL early learning composite | 0.12 | 0.06 | 1.98 | 0.09 | 0.08 | 0.05 | 1.69 | 0.14 |
| Gap-overlap disengagement | 0.01 | 0.02 | 0.53 | 0.61 | 0.01 | 0.02 | 0.83 | 0.43 |
| 18 months | | | | | | | | |
| MSEL early learning composite | −0.02 | 0.07 | −0.24 | 0.81 | 0.07 | 0.05 | 1.44 | 0.19 |
| Gap-overlap disengagement | −0.02 | 0.02 | −0.82 | 0.44 | −0.05 | 0.02 | −2.84 | **0.02**[a] |
| 24 months | | | | | | | | |
| MSEL early learning composite | - | - | - | - | 0.02 | 0.04 | 0.49 | 0.63 |
| Gap-overlap disengagement | - | - | - | - | −0.01 | 0.02 | −0.49 | 0.63 |

*Note*: Bold values indicates to highlight values that are statistically significant.
[a]Denotes that $p < .05$.

age. Firstly, the task demonstrated good internal consistency at both 18- and 24-months of age. Secondly, consistent with prior research using the task (Twomey et al., 2018, 2021), BabyScreen scores were higher at 24-months than at 18-months and this age effect remained even after the longer time allowed to complete the task at 24-months was accounted for. Thirdly, there was a significant association between performance at the two time points—infants who had higher scores at 18-months also had higher scores at 24-months. The improvements in BabyScreen scores over a period of 6 months are consistent with demonstrations that infancy is a time of rapid development across the domains of cognitive control and early emerging EF (Garon et al., 2008, 2014; Hendry et al., 2016). For example, Holmboe et al.'s (2021) tablet task also detected the development of, and stable individual differences in, inhibition between 18- and 24-months. Our findings are therefore consistent with prior work by suggesting that tasks like the BabyScreen have the potential to discriminate between early cognitive control abilities of younger and older infants. As it remains contested whether measures such as the ones presented in this paper can be interpreted as early underpinnings of more complex cognitive constructs such as EFs, some authors have suggested theoretical (Katus et al., 2023), performance-based (Diamond et al., 1985, 1997) and neurodevelopmental (Baird et al., 2002) links between measures of early cognitive control and later EFs. Future longitudinal work is needed to extend the stability of individual differences presented here into the preschool period

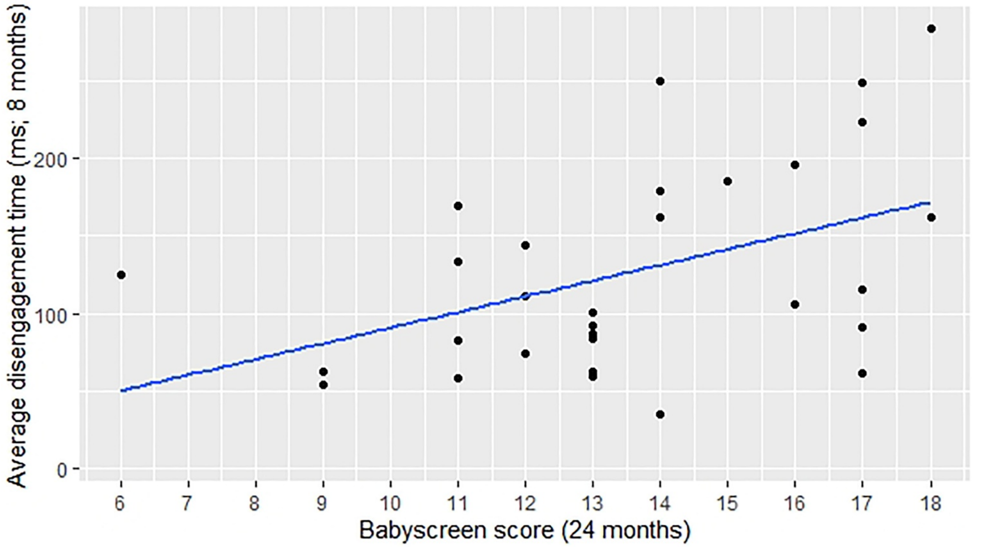



**FIGURE 5** Scatterplot showing the association between gap-overlap disengagement times at 8 months and BabyScreen scores at 24 months.

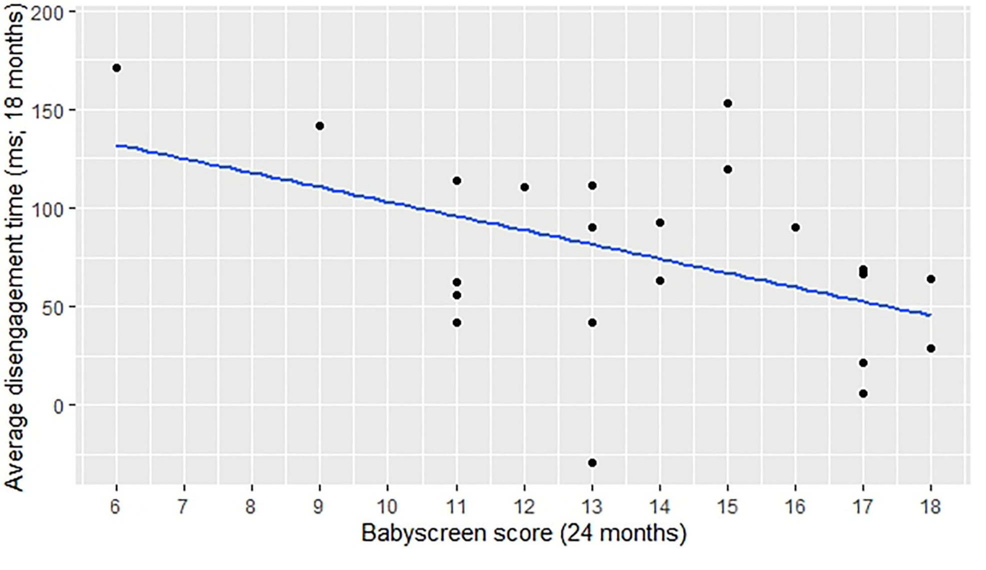



**FIGURE 6** Scatterplot showing the association between gap-overlap disengagement times at 18 months and BabyScreen scores at 24 months.

and assess whether early cognitive control measures, such as the one presented here, show domain-specificity in predicting later EFs.

Demographic factors (sex, household income, maternal education) and previous touchscreen use were not associated with BabyScreen scores. This is inconsistent with research showing that SES influences neurodevelopment (e.g., Lawson et al., 2018). The null finding here could be due to the homogenous, relatively high-SES sample in which most parents had high levels of education, meaning there was not enough variation to detect SES effects. On the other hand, the lack of influence of previous touchscreen use on BabyScreen scores is consistent with prior research (Twomey et al., 2018, 2021). However, most of the participants in the sample did have some prior touchscreen exposure, so these findings may have differed if a greater proportion had not used a tablet before.

## 4.2 | Associations between early cognitive control and general cognitive ability

We assessed associations between BabyScreen scores at 18- and 24-months and performance on the MSEL, a behavioral measure of global cognitive skills, both concurrently at these time points and longitudinally (at 5-, 8- and 12-months). Contrary to prior work showing a relationship between general cognitive ability measured by the Bayley Scales and BabyScreen scores (Casey et al., 2023; Twomey et al., 2021), there were no associations between the BabyScreen and the MSEL at any age. These findings are surprising given that prior work has demonstrated both concurrent relationships between MSEL scores and IC at 9-months (Holmboe et al., 2018) and longitudinal associations between MSEL at 2-years and EFs at 6-years (Stephens et al., 2018). It is possible that general cognitive abilities are more relevant for specific types of emerging EFs than others, as demonstrated in the association with IC (Holmboe et al., 2018), which was not captured by the BabyScreen's global score. Likewise, studies with populations with higher prevalence of cognitive delays (e.g., Yaari et al., 2018) report that differences in cognitive skills (measured behaviorally) typically become observable in the second year of life and, thus, we may have been less able to capture meaningful individual differences at the very early time points in this study.

Twomey et al. (2021) found that, among infants referred for neurodevelopmental assessment, those who had cognitive scores consistent with developmental delay on the Bayley Scales performed significantly worse on the BabyScreen than infants who had typical development. This is supported in Casey et al.'s (2023) work which found a predictive relationship between BabyScreen scores and Bayley Scales performance. It is possible that, while the BabyScreen can distinguish between infants with cognitive delay and those with typical development, it is less sensitive to individual differences among typically developing infants. This is compounded by the fact that the infants in our sample are predominantly from high-SES households and whose parents tended to have high levels of educational attainment. Finally, it is possible that the small sample size in this study did not have sufficient power to detect significant associations between the MSEL and BabyScreen.

## 4.3 | Attentional disengagement as a predictor of early cognitive control

One of the key aims of the present study was to assess whether attentional flexibility, measured through speed of attentional disengagement, in early infancy could predict emerging EF skills at 18- and 24-months. Prior work examining these associations has produced conflicting results, with some research suggesting that faster disengagement in early infancy was important for the development of early cognitive control and emerging EF, while ability to sustain attention became more relevant in later infancy (see Hendry et al., 2019 for a review). However, there was substantial variability in prior research in both the associations reported and the specific ages in which they occurred. Therefore, our study was well placed to address some of these inconsistencies and the paucity of research in general at this age point because of its longitudinal design and multiple study visits that were close in time.

We found that *slower* disengagement times at 8-months and *faster* disengagement at 18-months were associated with higher BabyScreen scores at 24-months. However, no significant relationships were found for disengagement times at 5-, 12- or 24-months. The findings are, to a degree, consistent with prior research that showed an association between slower disengagement at 12-month and higher effortful control at 18- and 24-months (Nakagawa & Sukigara, 2013). This prompted the idea that sustained attention, reflecting endogenous control of attention, at the onset of the second year of life, was an important factor in the development of cognitive control. However, similar work suggested that endogenous control of attention actually emerges earlier, at approximately 9-months of age (Kannass et al., 2006). In line with this work, it is possible that the association between slower disengagement at 8-months and cognitive control skills at 24-months found here reflects the emergence of sustained attention at this age and its potential importance for later EF development. Considering this alongside prior work, the results could indicate a developmental window, perhaps between 6 and 12 months where slower disengagement is advantageous for later cognitive control and EF.

The association between faster disengagement at 18-month and more advanced cognitive control skills at 24-month was contrary to predictions. Sacrey et al. (2013) suggest that, by 12-months of age, typically developing infants start to show more flexible attentional disengagement. They also found that at 12-months of age prolonged disengagement on the gap-overlap task distinguished typically developing infants from those with autism spectrum disorder. Our findings, therefore, support this work because, by 18-months of age, we would expect most typically developing infants in our sample to have fast and flexible attentional disengagement and prolonged disengagement to be associated with difficulties in cognitive abilities.

Finally, the lack of relationships between attentional disengagement measured at 5-, 12- and 24-months and cognitive control raises additional questions. Prior studies found no association between attentional disengagement at 4-month and later cognitive control skills (e.g., Holmboe et al., 2018). Therefore, it is possible that 5-months is too early to detect an association between attention and later EF-related skills. At 24-months, it is possible that attentional disengagement becomes more stable, and participants who showed delayed disengagement at 18-months, caught up. In line with this hypothesis, group differences in attentional disengagement reported between infants with ASD and typically developing controls have been found to be no longer significant by 36-months (Sacrey et al., 2013). It is also important to note that significant associations between attentional disengagement and BabyScreen performance were only found with BabyScreen scores collected at 24-months. This could reflect stabilization of cognitive control abilities at this age, making it a more reliable age to measure emerging EF skills than at 18-months.

While future research is required to understand the particular pattern of results that we have found, our work is among the first to examine associations between attention at multiple time points during the first 2 years of life and emergent cognitive control. Future longitudinal work would benefit from implementing a similar design with a substantially larger sample size. Furthermore, it would be valuable to include multiple measures of attention, particularly tasks that are specifically designed to measure attentional disengagement and sustained attention. Similarly, as discussed, an important direction for future research lies in the validation of the BabyScreen task against validated EF measures both concurrently and longitudinally to better understand their conceptual equivalence.

## 4.4 | Strengths, limitations, and implications for future work

This study has several strengths including the multi-method, longitudinal approach. The measurement of the same constructs over 5 time points in the first 2 years of life facilitated intricate investigation of the development of cognitive functions and how they relate to each other during infancy and toddlerhood. This is important as infancy is a time of rapid development of cognitive functions and abilities and relationships are likely to evolve rapidly so examination of multiple time points is needed to find critical points in development (Garon et al., 2008; Hendry et al., 2016). This design is relatively unique within the field with most studies taking measurements at one or two time points or using mixed-age cohorts. This study is also one of the first to measure emerging EFs with a tablet task in children under 2 years.

However, this study is not without limitations. Firstly, the sample size was small ($n = 60$ overall, with smaller samples for individual tests), limiting power to detect relationships (Button et al., 2013). Secondly, the sample, selected from the city of Cambridge and surrounding rural regions in the UK, was homogenous in terms of race, high-SES and high parental educational attainment. All families reported an annual household income of over £30,000 (cf. UK median of £29,900; ONS, 2021) and 78% of mothers had higher education qualifications (cf. 42% nationally; ONS, 2017). This is likely to explain the lack of variability and relatively high performance in MSEL scores and limits the generalizability of the findings.

## 4.5 | Conclusions

This study investigated the utility of a new tablet task in measuring cognitive control in infancy. The BabyScreen was found to be useful for measuring cognitive control and capturing consistent and improving performance over time with high internal consistency. While the task has been found to discriminate between general cognitive abilities in infants with and without neurodevelopmental delay in other studies, this finding was not replicated in the present, typically developing, sample. The relationship between cognitive control and attentional disengagement was complex, consistent with the highly varied literature.

Given the limitations of the small, high-SES, typically developing sample used here, it would be useful for future research to repeat the current study with a larger sample. In addition, the inclusion of infants with elevated familial likelihood, or showing signs of developmental neurodivergence would facilitate confirmation of previous results.

Overall, this study has demonstrated a useful tool for measuring emergent cognitive control and is one of the first to assess links with attention and cognitive skills using a longitudinal, multi-measure design. Use of the BabyScreen could support future research aiming to understand the development of cognitive control in infancy, to identify those with neurodivergence and may be used in combination with other measures to longitudinally track executive processes from infancy.

## ACKNOWLEDGMENTS

We would like to thank all families participating in this research, without whom this work would not have been possible. This research is funded by the Bill and Melinda Gates Foundation (grants OPP1061089 and OPP1127625). The Nutrition Theme at MRCG is supported by the MRC & the Department for International Development (DFID) under the MRC/DFID Concordat agreement (MRC Program MC-A760-5QX00). BM is supported by an ESRC

Secondary Data Analysis Initiative Grant (ES/V016601/1). SEM is supported by a Wellcome Trust Senior Research Fellowship (220225/Z/20/Z). SLF is supported by a UKRI Future Leaders Fellowship (grant number MR/S018425/1). *This work is supported by the NIHR GOSH BRC. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health*. The authors declare no conflicts of interest with regard to the funding source for this study. *The corresponding author's (Dr Bosiljka Milosavljevic) work was funded by UKRI grant* ES/V016601/1. *For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version arising. Furthermore, This work was supported, in whole or in part, by the Bill & Melinda Gates Foundation [Grant Numbers* OPP1061089 *and* OPP1127625*]. Under the grant conditions of the Foundation, a Creative Commons Attribution* 4.0 *Generic License has already been assigned to the Author Accepted Manuscript version that might arise from this submission*.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

Data supporting this paper will be made available subject to established data sharing agreements.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Macrae, E., Milosavljevic, B., Katus, L., Mason, L., Amadó, M. P., Rozhko, M., de Haan, M., Elwell, C. E., Moore, S. E., Lloyd-Fox, S. The BRIGHT Project Team, Crespo-Llado, M. M., Taylor, D., & Yelland, S. (2024). Cognitive control in infancy: Attentional predictors using a tablet-based measure. *Infancy*, *29*(4), 631–655. https://doi.org/10.1111/infa.12599