Using the TrackIt Task to Measure the Development of Selective Sustained Attention in Children Ages 2-7

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Abstract

The TrackIt task was developed as a measure of selective sustained attention that is developmentally-sensitive and able to partially separate exogenous and endogenous factors affecting attention regulation. However, these predictions have only been investigated within a limited set of parameters and age range (3-5 years). This preregistered study reports a systematic effort to examine performance on TrackIt in an expanded parameter space and age range. This study largely replicated and extended prior findings: across most implementations of the task, we found a medium-to-large effect of age and a small effect of condition. We also found that distractor errors were more likely given Low Exogenous support and in younger children. Contrary to the preregistered hypothesis, younger children did not benefit more from exogenous support than older children. Overall, these results contribute to the body of evidence that selective sustained attention (1) improves with age and (2) is bolstered by exogenous support.

Keywords: selective sustained attention; development of attention regulation; TrackIt

Introduction

The ability to maintain an attentive state over a period of time is often referred to as Sustained Attention. The term *Selective* Sustained Attention further refers to processing parts of sensory input at the exclusion of others over a period of time. Sustained attention is implicated in high-order cognition including learning (Fisher & Kloos, 2016; Oakes, Kannass, & Shaddy, 2002) and performance (Anobile, Stievano, & Burr, 2013; NICHD Early Child Care Research Network, 2003). Free-play assessments indicate that sustained attention develops markedly during the preschool years (Ruff & Lawson, 1990; Sarid & Breznitz, 1997); however, few experimental paradigms capture usable data for children in this age range (for review see Fisher & Kloos, 2016).

The TrackIt paradigm was designed to address this measurement gap (Fisher et al., 2013). In the TrackIt task, participants visually track a target geometric object moving among distractor objects on a grid. When all the objects disappear, participants identify the most recent location of the target object.

A noteworthy affordance of the TrackIt task is its ability to partially disentangle exogenous and endogenous factors that support selective sustained attention within a single task. Exogenous factors relate to characteristics of the stimuli (e.g., contrast or motion); whereas, endogenous factors refer to cognitive processes engaged to selectively focus attention (Colombo & Cheatham, 2006; Kane & Engle, 2002). Performing the TrackIt task necessarily implicates some endogenous factors, as the task is not so stimulating that children would perform it without being asked to do so. The relative importance of exogenous factors to TrackIt performance hinges on key target and/or distractor manipulations, resulting in Low and High Exogenous support conditions. Across both conditions, the experimenter provides task instructions and guidance in identifying the target object before the trial begins. In the Low Exogenous support condition, the target and distractor objects appear equal in salience after the trial begins. In contrast, in the High Exogenous support condition, the target is visually distinct from the distractors throughout the entire trial. The conditions are explained further in the methods section.

Prior studies suggest that nearly all preschool-age children can complete and provide usable data on the TrackIt task (in contrast to other assessments, such as child-appropriate versions of the Continuous Performance Test; see Fisher & Kloos, 2016). Performance on the TrackIt task shows considerable age-related improvement between 3 and 5 years of age (Fisher et al., 2013) showing that the task is developmentally-sensitive. Given the limited availability of developmentally-sensitive measures of sustained attention, some researchers began utilizing the TrackIt task. Their work has linked TrackIt performance to numeracy skills, proactive control, classroom learning, and prospective memory (Brueggemann and Gable, 2018; Doebel et al., 2017; Erickson et al., 2015; Mahy, Mazachowsky, & Pagobo, 2018).

Nonetheless, use of the TrackIt task as an individual differences measure may be premature given the limited prior efforts to validate the task with a broader range of parameters and age groups. Furthermore, most prior work focused on children's tracking accuracy; whereas, patterns of errors would be similarly informative in validating the task as a reasonable measure of sustained attention (Kim et al., 2017). The present study was designed to fill these gaps.

We conducted a cross-sectional study of the TrackIt task, in which we examined performance on TrackIt in an expanded parameter space and age range. We preregistered our hypotheses and analysis plan using aspredicted.org, and the anonymized preregistration is available here. Our main hypotheses concerned age and exogenous support.

We predicted a main effect of age, such that performance on the Track-It task (a measure of selective sustained attention) would improve across the age range 2-7 years. This prediction reflected observations of free-play assessments (Ruff & Lawson, 1990; Sarid & Breznitz, 1997) as well as prior empirical results using TrackIt (Fisher et al., 2013; Kim et al., 2017). We also anticipated a main effect of condition, such that performance would be better on trials with High Exogenous support, relative to those with Low Exogenous support. Recall that the High Exogenous support condition includes multiple overlapping physical cues for attention to the target. Deploying attention to physical properties of a stimulus is observed beginning in infancy (for review see Ruff & Rothbart, 2001). Even as endogenous cognitive processes become increasingly involved in attention across development, voluntary control of attention depends on active goal maintenance (Colombo & Cheatham, 2006) rather than stimulus-driven processes, making it harder to sustain. Prior TrackIt results also support this hypothesis (Fisher et al., 2013; Kim et al., 2017). We further hypothesized that the benefit of High Exogenous support (relative to Low Exogenous support) would be greater for younger children than for older children. This hypothesis again was based on the protracted development of endogenous factors for selecting and sustaining attention (Ruff & Rothbart, 2001) and prior empirical work with TrackIt (Kim et al., 2017).

Secondary hypotheses were that TrackIt performance would be a function of task difficulty (i.e., parameter combination) and that distractor errors—instances in which the participant identified the final location of a distractor object, rather than the target object—would decrease with age and with greater exogenous support. Among the error types, distractor errors were particularly informative in validating the TrackIt task as a measure of selective sustained attention (i.e., distractor errors suggest a failure to sustain attention to the target due to the presence of distractor objects, as compared to error types that are more suggestive of insufficient visuo-spatial resolution or failure to understand the task; see Response Types in the Method section).

In designing and preregistering the current study, we specified several changes to the task implementation, relative to prior work. We describe and justify those changes in the design section.

Method

Participants

The final sample consisted of 243 two- to seven-year-old children who were recruited from preschool centers, private and public elementary schools, and summer camps in a mid-sized Atlantic City. See Table 1 for a breakdown of participant ages. 72 additional children were excluded for failure to meet the preregistered memory criterion (n=36), failure to complete both sessions (n=10), and/or experimenter error (e.g., equipment failure or selecting incorrect parameters, n=26). In the final sample, of those reporting gender (93% of the sample), 51% of participants were male. Of those reporting ethnic and/or racial heritage (79% of the sample), 72% were white, 12% multiracial, and 10% African

Table 1: Sex and age statistics for each age and level

Age (years)	Difficulty Level 1		Difficulty Level 2		Difficulty Level 3		Difficulty Level 4	
	n/m/f/nb	Age Mean (*SD*)	n/m/f/nb	Age Mean (*SD*)	n/m/f/nb	Age Mean (*SD*)	n/m/f/nb	Age Mean (*SD*)
2 y.o	20/11/8	2.82 (.14)	--	--	--	--	--	--
3	21/8/9	3.59 (.23)	20/10/9	3.61 (.23)	--	--	--	--
4	20/10/9	4.43 (.30)	20/8/9/1 (1 non-binary)	4.48 (.26)	20/9/10	4.54 (.34)	--	--
5	--	--	21/7/12	5.53 (.25)	21/7/11	5.44 (.32)	20/9/8	5.55 (.26)
6	--	--	--	--	20/12/8	6.58 (.32)	20/11/9	6.55 (.32)
7	--	--	--	--	--	--	20/13/7	7.70 (.30)

Note: n/m/f/nb = sample size / # male/ # female / # non-binary (counts represent the participants who reported gender)

American or black. The remaining 6% of participants were spread among four additional ethnic and/or racial heritages.

Materials and Apparatus

Participants completed the TrackIt task (freely available at https://sites.google.com/andrew.cmu.edu/trackit/home). The task was presented on a Lenovo touchscreen laptop with the physical dimensions of 19.1 cm x 34.2 cm and pixel dimensions of 1920x1080. Participants were seated at a table facing the screen, which was located approximately 12 inches from the participants' faces.

TrackIt In the TrackIt task, participants are presented with a grid containing various shapes in a static image. Each shape is positioned in the middle of a grid cell. One of the shapes is encompassed in a red circle designating it as the target. Once the participant has identified the target shape (i.e., by pointing or correctly labeling it), the experimenter initiates the trial by pressing the spacebar. The red circle then disappears, and all shapes begin to move around the grid. After a minimum of 10 seconds, all shapes disappear. The participant is asked to choose the ending location of the target item which is recorded by the participant's touchscreen response. To avoid ambiguity, the target cell always disappears in the center of a grid cell.

After each trial, the participant is presented with a memory check where they were asked to select the target shape. This included four objects: the target shape and three other objects all distinct in color and shape. Following the child's touchscreen selection, a smiley face is presented on the screen. The child is told that this image does not represent a correct answer, but rather that the experimenter was happy that they were playing the game. See Figure 1 for a visual representation of a trial sequence.

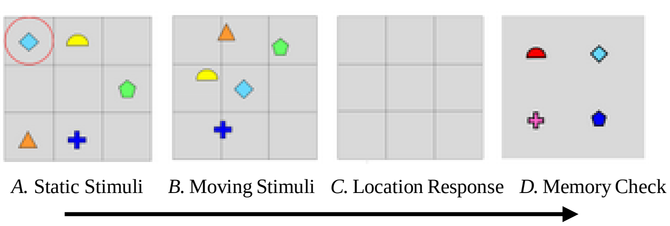

Figure 1: The TrackIt task pipeline. Panel A: static display of the stimuli before the trial starts; Panel B: the stimuli move along random trajectories during the trial; Panel C: response screen after the moving shapes disappear; Panel D: memory check.

Procedures

All participants were tested in a quiet room or hallway. Participants were told in child-friendly language that 1) all the shapes would start moving once the experimenter pressed a button, 2) their job was to visually follow the target shape, denoted with a red circle around it and 3) at some point all the shapes would disappear and they would be asked to find

Table 2: TrackIt parameter combinations used in each difficulty level

Difficulty	Age Group (years)	Grid Size	# of Distractors	Object Speed (pix/s)	Minimum Trial Length (s)
Level 1	2-4	2x2	2	300	10
Level 2	3-5	4x4	4	500	10
Level 3	4-6	6x6	6	500	10
Level 3	5-7	6x6	6	500	20

Note: pix/s = pixels/second

the shape's ending location. Children completed 11 trials per session. On the first trial, the experimenter followed the target shape with their index finger. This first trial served as demonstration and was subsequently excluded from analyses. The participants were then asked to complete the remaining 10 trials on their own, using only their eyes to track the target object.

Design

The path of each shape was randomized. Object motion display was set to 30 frames per second. The parameters—grid size, number of distractors, speed of objects, and minimum trial length were varied to create four combinations of parameters, or difficulty levels (see Table 2). The goal was not to systematically explore the effects of individual parameters but rather to define sets of parameters that would be likely to change the task difficulty, in order to support the project goal of examining performance on TrackIt in an expanded parameter space and age range. The parameter combinations (difficulty levels) were selected based on previously used parameters with a separate group of 3- to 5-year-old children (Kim et al., 2017) and via pilot testing with 2-, 6-, and 7-year-olds. Separate groups of children were tested in each difficulty level. The ages selected for each difficulty level were chosen as such to minimize the occurrence of floor and ceiling effects.

Conditions Each child was tested in a Low Exogenous and a High Exogenous support condition, occurring on separate days. Most children completed the sessions within 2 weeks of one another, except for 11% children who completed the second session up to 4.7 weeks after the first. The average delay between sessions was 8.9 days (*SD* = 4.8 days). The order of the conditions was counterbalanced across all ages.

In the Low Exogenous support condition, all distracter shapes were heterogeneous, and the sizes of all objects remained constant throughout the trial, such that the target object for each trial was equal in salience to the distractors once the trial began (see Figure 2). In the High Exogenous support condition, the distractors were homogenous, and the target shape continuously oscillated between its original size and 50% of its size bigger and smaller throughout the trial. The manipulation of distractor composition between Exogenous support conditions in this study matches that of the first-reported implementation of the TrackIt task (Fisher

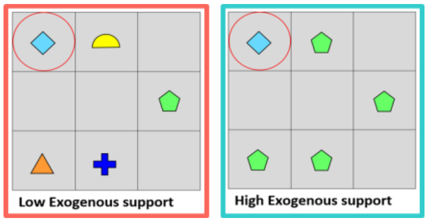

Figure 2: Exogenous Support Conditions

et al., 2013). However, the target size manipulation included in our study was not included in the originally reported study. The reason for this manipulation is explained below.

Each grid cell in the initial version of the TrackIt task (Fisher et al., 2013) included a popular cartoon character. These background images were displayed throughout the trial and invoked by the participants when identifying the final location of the target. As the current study utilized touchscreen technology for reporting the final location of the target, we removed the cartoon characters entirely and replaced them with alternating gray and white grid cells. We expected that removing the high-interest cartoon characters would focus children's attention on the TrackIt task to a greater degree and possibly reduce the difference between conditions. Accordingly, in an effort to preserve the ability of the TrackIt task to partially separate the exogenous and endogenous factors affecting attention regulation, we sought to enhance the difference between the Low and High Exogenous support conditions. As noted above, we included an additional manipulation of target size to enhance the salience of the target relative to distractors in the High Exogenous support condition. Thus, the conditions in this paper were designed to maximize the differences between Exogenous support conditions following the removal of background images.

Memory Criteria

An incorrect response to the memory check may indicate that the participant did not understand the task and/or did not retain in working memory the target shape for that trial. In such cases, an incorrect response to the final location of the target would not necessarily implicate a failure in selective sustained attention. In contrast, when a participant *does* correctly identify the target shape in the memory check but fails to identify its final location, this pattern of results is more likely to indicate a failure in sustained attention (particularly when the participant also commits particular types of errors, discussed below).

Accordingly, in order to measure our main construct of selective sustained attention, we focused a majority of our analyses on those trials for which the participant correctly answers the memory check. To facilitate this goal and to best compare participants' performance across conditions, we included in our final sample only participants who answered at least half of the memory trials correctly in both sessions. This preregistered criterion focuses our data analysis and reporting on those trials for which incorrect responses most likely reflect failures in sustained attention, rather than working memory demands or general failures to coordinate the task demands.

Application of this criteria resulted in excluding the data of 36 participants, and we continued data collection until we collected data from 20 participants per cell who met the memory inclusion criteria (final intended sample size of 240 children; we oversampled by one participant in each of three cells and so report data from 243 final participants). The participants whose data was excluded differed from the rest of the sample in that they were younger, with most being age 3. Note that we did not apply the memory exclusion criteria to data from two-year-old participants, as only 2 of 20 two-year-old participants met the criteria for inclusion.

Response Types

Unlike most prior studies using TrackIt, this study analyzed type of errors children tended to make when they chose the incorrect location. These tracking errors were classified by the incorrect cell chosen by the participant in relation to the final position of the target and distractor objects. These error types originally were described in Kim et al. (2017). Error classifications were applied to difficulty levels 2-4 only, because such analyses are not meaningful for Level 1 due to the small grid size.

Seven types of responses were considered. Figure 3 represents the final frame of a TrackIt trial, and the coordinates of response cells corresponding to each error type are noted parenthetically following the definitions of the error types. Note that in all cases adjacency is defined as being within one horizontal, vertical, or diagonal step of a given cell.

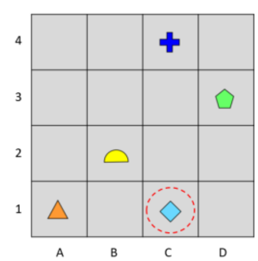

Figure 3: Sample Final Frame of a TrackIt Trial

Participant responses were classified as "Target (Correct)" when the response cell contained only the target (C1). "Target Spatial Resolution Error" occurred when the response cell was adjacent to the correct grid cell, but not adjacent to any distractor cells (D1). "Ambiguous Response (Correct)" occurred when the response cell contained both the target and a distractor (n/a for this figure, and the target always crossed and/or landed in front of distractors). "Ambiguous Spatial Resolution Error" indicated that the response cell was adjacent to both a distracter cell and the target (B1, C2, D2). "Distractor Error" occurred when the response cell contained only a distractor (A1, B2, D3, C4) and "Distractor Spatial Resolution Error" referred to a response cell that was adjacent to a distractor, but not adjacent to the target cell (A2, A3, B3, C3, B4, D4). Finally, “Random Error” captured instances in which the response cell did not contain a distractor, nor was it adjacent to a distractor or the target (A4).

Results and Discussion

Age and Task Level

For each participant, we calculated an average accuracy score i.e., the proportion of ten trials for which the participant correctly identified the grid cell in which the target object disappeared. For the ages and difficulty levels tested, participants' average accuracy was below functional ceiling—here defined as 90 percent—and above chance, where chance-level performance for each level is based on the grid size i.e., Level 1, 2x2: 0.25; Level 2, 4x4: 0.063; Levels 3 and 4, 6x6: 0.028 (*ts*(19)>4.84, *ps*<.001), except for two-year-old children (*t*(19)=1.76, *p*=.09). Separate analysis of two-year-old children's patterns of performance revealed that perseveration to a single grid cell and still-developing fine motor skills contributed to their chance-level accuracy on the TrackIt task (Maxwell, Keebler, & Fisher, 2020). Due to such confounds in studying two-year-old children's sustained attention using the TrackIt task, we focus our analysis and reporting in the subsequent sections of this paper on difficulty levels 2-4 (children ages 3-7).

Understanding variability between participants may be helpful to future investigators planning to use TrackIt. The mean, standard deviation, and range of accuracy for each age group (collapsed across levels and conditions) were as follows: age 3: mean 0.23, *SD* 0.15, range 0.00-0.55; age 4: mean 0.58, *SD* 0.27, range 0.10-0.90; age 5: mean 0.75, *SD* 0.21, range 0.20-1.00; age 6: mean 0.84, *SD* 0.18, range 0.45-1.00; age 7: mean 0.88, *SD* 0.10, range 0.70-1.00).

To investigate possible effects of participant age and condition, accuracy scores were submitted to a 2-way analysis of variance (ANOVA) with age as a between-subject factor and condition as a within-subject factor. This analysis was applied separately to each of the three difficulty levels. For all levels, the results indicated main effects of age and Exogenous support condition, but no age-by-condition interactions. See Figure 4 for a visualization and Table 3 for the test statistics.

Table 3: Effects of Age and Condition on Accuracy

	Main Effect of Age	Main Effect of Condition	Interaction of Age and Condition
Level 2	F (2, 58) = 42.33, $p < .001$, $\eta_p^2 = 0.59$	F (1, 58) = 14.74, $p < .001$, $\eta_p^2 = 0.20$	F (2, 58) = 0.28, $p = .75$
Level 3	F (2, 58) = 12.70, $p < .001$, $\eta_p^2 = 0.30$	F (1, 58) = 5.60, $p = .02$, $\eta_p^2 = 0.09$	F (2, 58) = 0.52, $p = .60$
Level 4	F (2, 57) = 7.56, $p < .01$, $\eta_p^2 = 0.21$	F (1, 57) = 9.04, $p < .01$, $\eta_p^2 = 0.14$	F (2, 57) = 0.87, $p = .43$

Note: η_p^2 = partial eta-squared

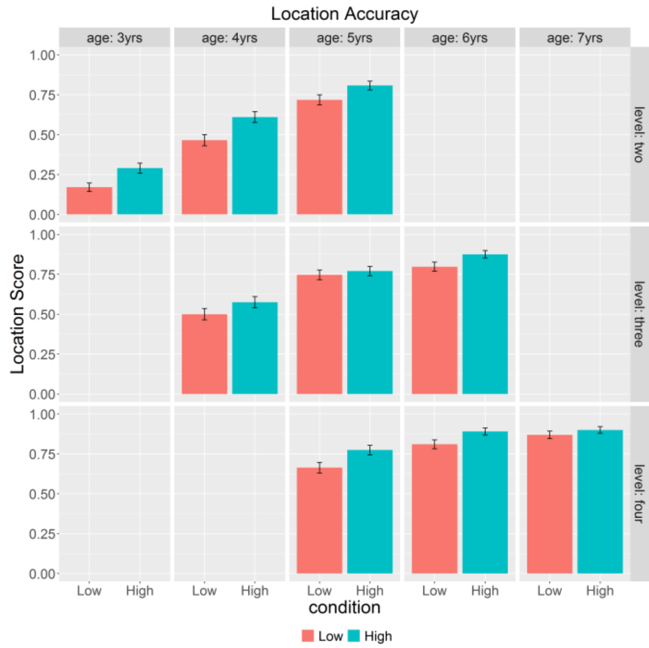

Figure 4: Accuracy by Age, Level, and Condition

These effects also held for memory-corrected data, that is, when the analyses were conducted on only those trials for which the participant correctly answered the memory check (*ps*<.02) except that in Level 3 the effect of condition was no longer significant (F(1, 58)=2.06, *p*=.16).

We tested the effect of difficulty level on performance for age groups completing two or more of the difficulty levels 2-4. Contrary to predictions, we found no effect of difficulty level for children aged 4 (F(1, 38)=1.50, *p*=.97), 5 (F(2, 59)=0.37, *p*=.69), or 6 (F(1, 38)=0.07, *p*=.79).

Response Types

Figure 5 indicates the distribution of response types by age and level for the Low and High Exogenous support conditions, after controlling for memory accuracy. We were particularly interested in studying the occurrence of distractor errors to validate the TrackIt task as a measure of selective sustained attention. Across age groups and levels, a significant proportion of errors were distractor-related errors (distractor, distractor spatial resolution, and ambiguous errors).

We hypothesized that the proportion of trials that yield distractor errors would be greater in the Low Exogenous support condition relative to the High Exogenous support condition and that the proportion of trials yielding distractor errors would decrease with age between ages 2 and 7.

To test these hypotheses, we conducted a mixed ANOVA on the effect of age (between-subject variable) and condition (within-subject variable) on the proportion of trials that yielded distractor errors for each of Levels 2, 3, and 4. Details of the results of these analyses are shown in Table 4. The analyses largely supported the hypotheses above. Specifically, we found main effects of age for each level (all

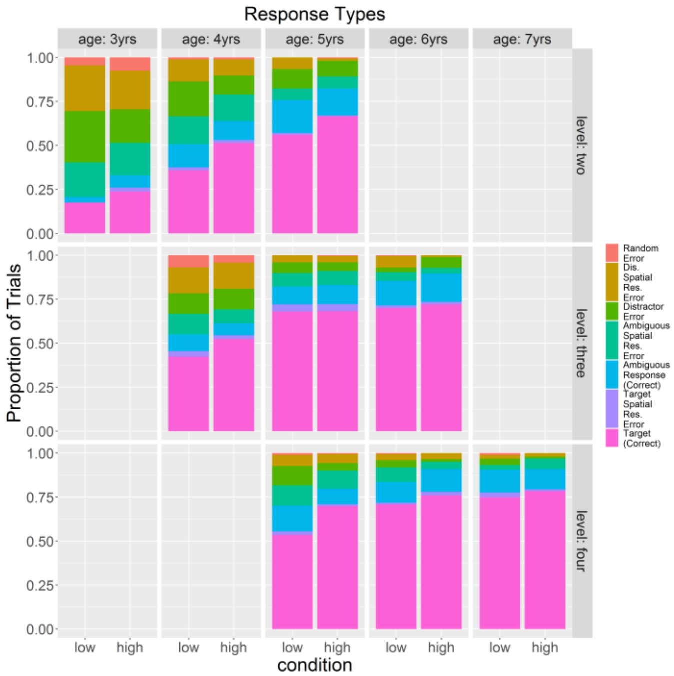

Figure 5: Response Types by Age, Level, and Condition

ps≤ .02, all $\eta_p^2 \geq .12$) and main effects of condition for Levels 2 and 4 (both *ps*≤ .01, both $\eta_p^2 \geq .11$) (although it should be noted that there was no significant effect of condition in Level 3). There were no significant interactions between age and condition, all *ps*≥ .41.

Table 4: Effects of Age and Condition on Distractor Errors

	Main Effect of Age	Main Effect of Condition	Interaction of Age and Condition
Level 2	F (2, 58) = 6.33, p < .01, $\eta_p^2 = 0.18$	F (1, 58) = 7.81, *p* < .01, $\eta_p^2 = 0.12$	F (2, 58) = 0.83, *p* = .41
Level 3	F (2, 58) = 3.96, p = .02, $\eta_p^2 = 0.12$	F (1, 58) = 0.18, *p* = .67, $\eta_p^2 = 0.003$	F (2, 58) = 0.70, *p* = .50
Level 4	F (2, 57) = 4.16, *p* = .02, $\eta_p^2 = 0.13$	F (1, 57) = 6.96, *p* = .01, $\eta_p^2 = 0.11$	F (2, 57) = 0.86, *p* = .43

Discussion

Many results of the current study replicated prior empirical work and reflected what is known about attention development. We found effects of age and exogenous support condition on children's TrackIt accuracy, supporting that the paradigm is developmentally-sensitive to selective sustained attention across a wider range of parameters and ages than previously studied. Still, Level 2—the level for which the parameter space and age-range most closely reflected prior work—showed the greatest effects of age and condition, based on the effect sizes reported in Table 3. This level also showed the strongest predicted patterns of distractor-type errors. In contrast to the pre-registered hypothesis, we did not find support for younger children benefitting more from exogenous support relative to older children. We may have been underpowered to detect an interaction, or significant growth in endogenous control of attention might have occurred outside of the age ranges studied.

The difficulty levels and associated age ranges selected for this study seem to comprise appropriate parameters for individual differences studies of selective sustained attention due to the range in participant scores and the lack of observed floor or ceiling effects. This said, parameter selection for the TrackIt task may be more flexible than previously supposed. Contrary to our hypothesis, the difficulty levels we defined did not significantly affect accuracy. In fact, for age groups completing two or more levels of the task, performance was surprisingly consistent across the parameter combinations utilized. This finding may suggest that the TrackIt paradigm is more robust to varied parameter settings than anticipated.

Conclusion

The results contribute to the body of evidence that selective sustained attention (1) improves with age and (2) is bolstered by exogenous support. The analysis of error types provides additional evidence that the TrackIt task measures selective sustained attention, given that a significant proportion of errors are distractor-related errors (distractor, distractor spatial resolution, and ambiguous errors). Further, individual variability in task performance for the age and parameter combinations studied supports the use of TrackIt to study individual differences in selective sustained attention.

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