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Does Children's Shape Knowledge Contribute to Age-Related Improvements in Selective Sustained Attention Measured in a TrackIt Task?

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Abstract

The ability to maintain attentive state over a period of time (i.e., Selective Sustained Attention) is important for higher-order cognition but challenging to assess in preschool-age children. The TrackIt task was developed to address this challenge and has been argued to be sensitive to age-related differences in selective sustained attention in 3- to 5-year-old children. However, it remains unclear whether this improvement with age also (or predominantly) reflects improvement in children's knowledge of different shapes used as stimuli in this task in prior studies. The current study addressed this possibility. Consistent with prior studies, we found clear age-related improvement in performance on TrackIt. However, we did not find evidence that shape knowledge played a role in TrackIt performance for children aged 2 to 5, suggesting that increased knowledge of geometric shapes is not sufficient to explain age-related improvement in performance and helping to validate TrackIt as an assessment of Selective Sustained Attention.

Keywords: selective sustained attention; TrackIt

Introduction

The ability to maintain attentive state over a period of time (often referred to as Focused or Selective Sustained Attention) is important for higher-order cognition, including learning (e.g., Fisher & Kloos, 2016; Oakes, Kannass, & Shaddy, 2002). This ability undergoes marked development during the preschool years as shown by the increased time that children spend in this state during free play assessments of selective sustained attention (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. In the TrackIt task, participants visually track a target object moving along a random trajectory on a grid, while simultaneously ignoring distractor objects. At the conclusion of the trial, the objects disappear and the participant indicates the final location of the target on the grid. Prior studies suggest that nearly all preschool-age children can complete and provide usable data on this task (in contrast to other assessments, such as downward extension of the Continuous Performance Test; see Fisher & Kloos, 2016). Performance on this task shows considerable age-related improvement between 3 and 5 years of age (Fisher et al., 2013) showing that the task is developmentally sensitive. Importantly to this paper, the target and distractor objects in the TrackIt task are usually selected from a set of geometric forms (circle, diamond, square, triangle, pentagon) and iconic shapes (crescent, cross, arrow, semi-circle).

Age-related improvement in performance on the TrackIt task during the preschool period has been interpreted as improvement in selective sustained attention (Brueggemann & Gable, 2018; Erickson et al., 2015; Fisher et al., 2013). However, shape knowledge is also known to improve during the preschool period (e.g., Clements et al., 1999; Verdine et al., 2016) and could be an important element of successful completion of the TrackIt task. Therefore, it remains unclear whether increased shape knowledge may account for the age-related improvement in performance on the TrackIt task. This finding would challenge prior interpretations that age-related changes in TrackIt performance primarily reflect improvement in selective sustained attention.

Shape knowledge may play a role in the task in the following way. When distractors are unique from each other and from the target, all objects in the task are comparable in salience (Fisher et al., 2013). Therefore, participants need to encode the identity of the target object in order to successfully complete the task. Children may encode the identity of the target object by maintaining its visual representation in working memory and by using labels to refer to object shape. Younger children whose shape knowledge is still developing may encode the identity of the target object less robustly than older children with greater shape knowledge.

There is indirect evidence to support this possibility. Vales and Smith (2015) provided evidence that object labels help children maintain precise representations of objects in working memory during a visual search task. Consistent with this explanation, Doebel et al. (2018) showed that preschool children were better at a modified TrackIt task with novel shapes (for which children did not have consistent labels) when experimenters provided labels. This result was found even though children were able to identify the shape from a set of choices after the task was complete (i.e., a memory check). Thus, although children completing TrackIt with geometric forms have demonstrated memory check accuracy that is well above chance, the encoding necessary to recognize the target object after the trial may be insufficient to support accuracy on the main task. Instead, children's own knowledge of shape names may facilitate their performance on the TrackIt task when the experimenter does not provide labels for the target objects (as is the standard procedure on the TrackIt task) by enabling the children to self-generate labels of the targets.

It is possible that children may use non-canonical names for shapes when they do not know the proper labels. For example, when asked to describe geometric forms, Clements et al. (1999) found that young children tended to invoke visual descriptions of geometric forms (e.g., "pointy," "round", or "skinny"). However, such visual descriptions comprise non-unique labels (e.g., both a diamond and a triangle could fit the visual description "pointy"). Therefore, if younger children generate visual descriptor labels when they do not know the canonical labels, these visual descriptor labels may still be less helpful for encoding the target identity than canonical labels that are more likely to be known (and self-generated) by older children.

In the current study we examined the possibility that age-related improvement in performance on the TrackIt task may be attributed, at least partially, to age-related increase in shape knowledge.

Experiment 1

Method

Participants 90 two- to five-year old children (M = 3.89 years, SD = 9.4 months, range 2.58 to 5.77 years) participated in the study. Participants were drawn from public and private preschool and kindergarten programs. The data reported are part of a larger cross-sectional study for which data collection is in progress, that has a final intended sample size of 240 participants aged 2-7 years. That larger study is preregistered at aspredicted.org, and the anonymized preregistration is available here. The target shape analyses reported in this paper were not pre-registered. Of the 90 participants recruited for this study, 3 participants were excluded from the analysis because they refused or otherwise failed to complete ten trials or due to experimenter error.

Materials and Apparatus The TrackIt task (freely available at http://www.psy.cmu.edu/~trackit) was presented on a Lenovo laptop screen with physical dimensions 19.1 cm x 34.2 cm and pixel dimensions 1920x1080 pixels. Participants were seated at a desk facing the screen with their heads about 12 inches away from the screen. For each trial, the target and distractor objects were randomly picked without replacement from a set of unique objects spanning 9 different shapes with 9 different color possibilities (81objects in total). See Figure 1 for examples.

We expect that young children have differential knowledge of the shape stimuli used in the TrackIt task (i.e., children are likely to know some, but not all, of the nine shapes and their associated labels). Because encoding the identity of the target object is necessary to complete the TrackIt task, greater knowledge of a target shape may result in better accuracy on trials with that target shape relative to trials with a less familiar shape. To represent the relative familiarity of the target shapes to one another, we assessed the frequency of the stimuli using ChildFreq (Bååth, 2010), a tool that extracts word frequencies from the American and British parts of the Childes database (MacWhinney, 2010). In particular, we found the frequency of the canonical names for the nine shapes over the for the age range 12-35 months (see Table 1). As is shown in Table 1, there was considerable variability in the frequency of the stimuli, ranging from 1 to 273 occurrences per million words.

Table 1: Frequency of Stimuli in the Childes Database

Stimuli	**Occurrences per 1,000,000 Words**
Circle	273
Triangle	165
Square	126
Cross	91
Diamond	26
Pentagon	11
Arrow	1
Crescent	1
Semicircle	1

Procedures The experimenter administered the TrackIt task to participants in a quiet room or hallway. In the TrackIt task, participants were asked to visually track a single target object as it moved on a grid among moving distractor objects. At the beginning of each trial, the objects appeared on the grid, centered in distinct grid cells, and the target object was indicated by a red circle around it. The initial positions of the objects were randomized. At the beginning of the task, participants were told that: 1) the objects will start moving around the grid when the experimenter presses a button; 2) the goal is to follow the target object with their eyes; 3) at some point the objects will suddenly disappear, and their job is to point to where the target object was when it disappeared.

The experimenter started each trial with a button press after ensuring the participant was ready to begin. Upon starting the trial, the red circle disappeared, and the objects began to move in curvilinear trajectories from grid cell to grid cell at a constant speed. At the end of each trial, all objects disappeared from the screen, and the participants were asked to indicate with their finger (on the touch screen) which grid cell the target object was last in before it disappeared. Each trial was followed by a memory check screen and a smiley face. Participants were told that the smile did not indicate a correct answer and rather that we were happy they were playing our game. See Figure 1 for a diagram of the task sequence.

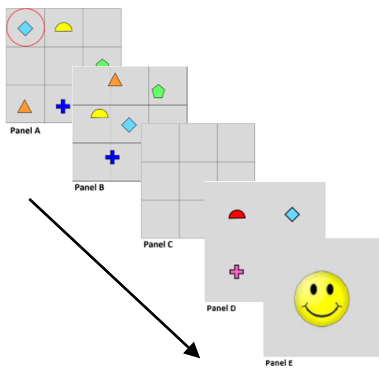

Figure 1: The TrackIt task pipeline. Panel A: static display of the stimuli before the trial starts; Panel B: the stimuli move along random trajectories during the trial; Panel C: response screen after the moving shapes disappear; Panel D: memory check; Panel E: a smiley face at the end of the trial.

Participants completed 11 trials of the task. The first trial was a practice trial and was completed with assistance from the experimenter who traced the moving target with their index finger. The first trial was accordingly omitted from analysis. Participants were then told that they would need to complete the rest of the task by themselves, tracking the target with their eyes only.

Design The sequence of positions in the path of each of the objects was randomized. Object motion display was set to 30 frames per second. The minimum trial length was set to 10 milliseconds. The parameters—grid size, number of distractors, and speed of objects—were determined by prior testing in TrackIt with a separate group of 3- to 5-year old children (Kim et al., 2017) and via pilot testing with two-year-olds. The parameters were organized according to participant age and difficulty level as seen in Table 2.

Table 2: TrackIt parameter combination used in each difficulty level

Difficulty	Age Group (years)	Grid Size	# of Distractors	Object Speed (pix/s)
Level 1	2-4	2x2	2	300
Level 2	3-5	4x4	4	500

Note: pix/s = pixels/second

Separate groups of participants were tested in each difficulty level. We did not complete testing for age and level combinations that were likely to produce floor or ceiling effects. The final sample size per age and difficulty level is presented in Table 3.

Table 3: Sample sizes and age statistics for each age group, for each difficulty level

Age (years)	Difficulty Level 1		Difficulty Level 2	
	n/m/f	Age Mean (Std)	n/m/f	Age Mean (Std)
2 y.o.	13/8/5	2.89 (0.12)	--	--
3	19/7/12	3.53 (0.27)	20/12/8	3.56 (0.24)
4	14/7/7	4.39 (0.26)	12/5/6 (1 not reported)	4.31 (0.15)
5	--	--	9/4/5	5.48 (0.22)

Note: n/m/f = sample size / # male/ # female.

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. To investigate possible effects of participant age and task difficulty level, accuracy scores were submitted to a 2-way analysis of variance (ANOVA) with age and difficulty level as between-subject factors. This analysis indicated main effects of age (F (3, 81) = 11.40, p < .001) and difficulty level (F (1, 81) = 19.16, p < .001), but no age-by-difficulty interaction (F (1, 81) = 1.65, p = .20) (See Figure 2).

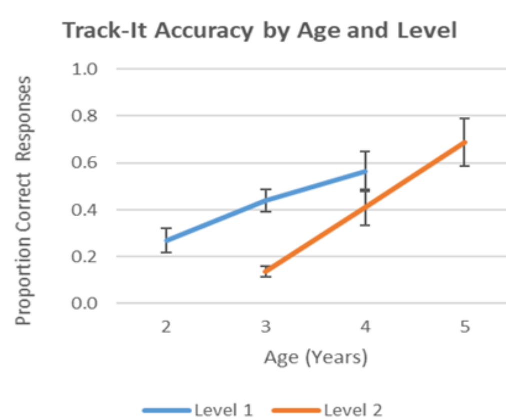

Figure 2: TrackIt accuracy improved with age for participants tested in Levels 1 and 2.

Post-hoc Tukey's tests showed that, for Level 1, the tracking accuracy of 4-year olds was significantly above that of 2-year olds (adjusted p = .02) but not 3-year olds (adjusted p = .44). For Level 2, the tracking accuracy of 4-year olds was significantly above that of 3-year olds (adjusted p = .03). However, the tracking accuracy of 5-year olds was not significantly above that of 4-year olds (adjusted p = .10). Nonetheless, there is an emergence of developmental trends that are consistent with Fisher et al. 2013 and Kim et al. 2017 and further, planned data collection (i.e., to bring the number of participants in each cell to 20) will shed light on any further age-related differences. Post-hoc Tukey's tests also showed that 3-year olds performed significantly better in Difficulty Level 1 than in Difficulty Level 2 (p < .01). Surprisingly, 4-year-olds did not show a significant difference in performance at Difficulty Levels 1 and 2 (adjusted p = .64).

For all combinations of difficulty level and age group, TrackIt accuracy was above chance (25% given four response options in Level 1 and 6.25% given 16 response options in Level 2, all one-sample t s > 3.62, p s < .001), except for two-year-old children completing Difficulty Level 1 (one-sample t (12) = 0.63, p = .54). This result indicates that two-year-olds did not differ from chance performance on the TrackIt task.

Shape Frequency Next we assessed the possibility that the frequency of a target shape influenced children's performance on trials with that target shape. The average proportion of correct trials, sorted by target shape, ranged from 0.32 (diamond) to 0.44 (crescent). To determine whether TrackIt performance varied significantly by shape frequency, we conducted a logistic regression using shape frequency to predict accurate TrackIt responses while controlling for participant age and task difficulty level. Results of the regression indicated that participant age and task difficulty level, but not frequency of target shape, were associated with TrackIt performance (see Table 4).

Table 4. Results from the logistic regression analysis: target shape frequency, difficulty level, and participant age as predictors of correct answer on a trial of TrackIt

Predictor	*B*	*SE B*	Wald	*P*	*df*
Shape Frequency	-0.00	0.00	-6.68	.89	868
Difficulty Level	-0.54	0.08	-0.14	<.001	868
Participant Age	0.98	0.10	-6.45	<.001	868

Similarly, results of a Pearson correlation did not indicate an association between frequency of a target shape and children's average TrackIt accuracy on trials of that target (r = -0.01, p = .72). See Figure 3.

Based on these results, it does not appear that shape knowledge can account for any variability in TrackIt performance, a finding that helps to validate TrackIt as a measure of selective sustained attention. However, there are several cautions in using frequency data as a proxy for shape knowledge. Some of these concerns are grammatical/technical in nature e.g., given the nature of the data, it is unknown what proportion of word utterances co-occurred with a concrete or pictorial referent, and this co-occurrence structure might matter for the encoding of the referent shapes.

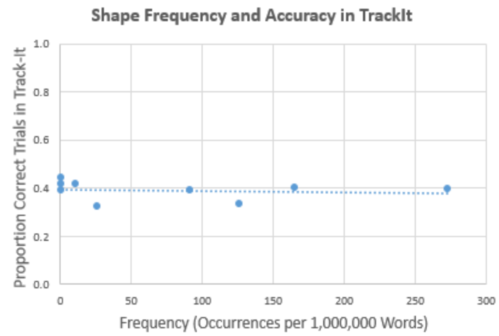

Figure 3: Corpus frequency of target shapes did not account for variability in TrackIt performance.

Relatedly, some of the stimuli names (see column 1 of Table 1) can be used as verbs with semantically-related meanings to the shapes whose names they share (e.g., circle, cross) and/or adjectives with meanings unrelated to the shapes whose name they share (e.g., cross). Some stimuli are both the nominal and adjectival form of the shape name (e.g., square); whereas, other shapes have a morphologically related but distinct adjective form (e.g., circular, triangular). These nuances might bias to the number of occurrences of each target shape in the ChildFreq database. Perhaps more critically, the nature of interactions captured in the Childes database may be biased toward free-play and informal interactions, rather than formal educational experiences. Accordingly, it might underestimate the frequency of less-common shape names, to which children might be exposed in other, more explicitly educational interactions not captured in the data.

Nonetheless, we posit that—for this age group—the relative frequencies observed likely comprise reasonable approximations of shape familiarity i.e., circle, triangle and square are the most common and early-emerging shape names in our stimuli set, with crescent and semi-circle being significantly less frequent. However, to address the concerns about using relative frequencies as a proxy for children's shape knowledge, in Experiment 2 we directly assessed the shape knowledge of three- to five-year-old children, as described below.

Experiment 2

Method

Participants We tested 32 participants to assess children's knowledge of the shapes (M = 4.47 years, SD = 9.3 months, range 3.24 to 5.84 years). Participants were drawn from preschool and kindergarten programs. 16 of these children were also participants in Experiment 1 (M = 4.29 years, *SD* = 8.7 months, range 3.35 to 5.70 years) and completed the shape knowledge task an average of 9.7 weeks after the TrackIt task. It is unlikely that participation in the TrackIt task affected children's performance on the shape knowledge task. The total sample for Experiment 2 included 11 three-year-olds (8 females, *M* = 3.56 years, *SD* = 1.9 months); 11 four-year-olds (6 females, *M* = 4.52 years, *SD* = 3.0 months); and 10 five-year-olds (7 females, *M* = 5.40 years, *SD* = 2.7 months).

Given that (1) two-year-olds were at chance in identifying the last location visited by the target shape in Experiment 1 and (2) pilot testing indicated that two-year-old children had difficulty producing verbal responses on the shape knowledge assessment, we did not include this age group in Experiment 2.

Materials and Apparatus The physical equipment and child seating position is identical to those of Experiment 1. Shapes presented were the set of TrackIt stimuli, made identical in color and equated for overall size (see Figure 4).

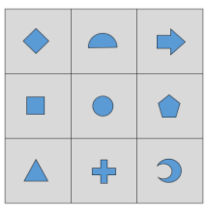

Figure 4**:** The set of geometric forms and iconic shapes comprising the TrackIt stimuli, presented on a single grid.

Procedures Shapes were displayed one at a time in the center of a gray screen. Children were instructed to provide verbally the name of each shape and prompted to "make their best guess" as necessary. No feedback was provided on the accuracy of children's responses. The experimenter demonstrated the task across 6 practice trials that presented the stimuli star, heart, and oval two times each. The nine stimuli were sampled without replacement, after which the block of nine was repeated two more times for a total of 27 trials (3 presentations of each of the 9 target shapes).

Results and Discussion

As expected based on the ChildFreq statistics, children demonstrated superior knowledge of high-frequency shape names (e.g., circle, triangle) relative to low-frequency shape names (e.g., crescent, semicircle). Results of the Pearson correlation indicated that there was a positive association between shape frequency and children's shape knowledge, ($r = .82$, $p < .01$) (Figure 5). Accordingly, we have put forth two complementary approaches for assessing shape familiarity for the TrackIt stimuli.

To assess possible age-related changes in shape knowledge, we conducted an ANOVA on children's shape

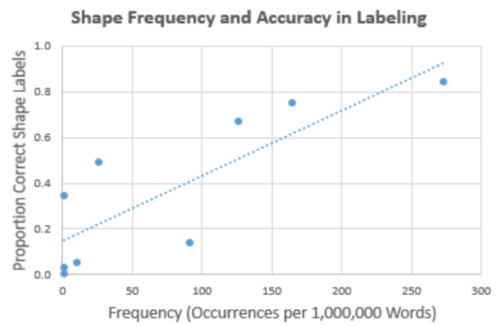

Figure 5: Children's accuracy in labeling shapes positively correlated with the frequency of those names in the corpus.

knowledge using participant age and shape frequency predictors. This analysis indicated main effects of age (F (1, 284) = 19.85, $p < .001$) and shape frequency (F (1, 284) = 147.40, $p < .001$).

Despite finding better shape knowledge in older children than in younger children, we did not find a relationship between children's knowledge of shapes and average performance on TrackIt trials with that target shape (see Figure 6 for a visualization).

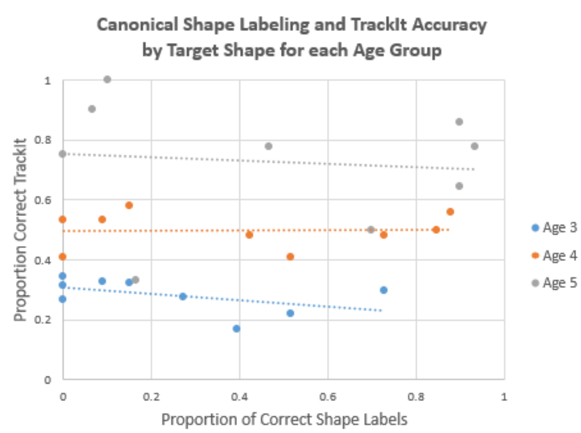

Figure 6: Children's accuracy in shape labeling and on TrackIt trials with that target shape, by age.

We further assessed this relationship using a logistic regression on trial accuracy by proportion correct shape labels with a control for difficulty level (Table 5).

Table 5. Results from the logistic regression analysis: proportion correct shape labels and difficulty level as predictors of producing a correct answer on a trial of TrackIt

Predictor	*B*	*SE B*	Wald	*P*	*df*
Shape Label	-0.26	0.23	-1.15	.25	868
Difficulty Level	-0.35	0.14	-2.48	.01	868

Similarly, results of a Pearson correlation did not indicate an association between average ability to name a target shape and accuracy on trials of that target (r = -0.04, p = .24).

Other Names The results above are based on children's productive shape knowledge of a single canonical name for each target shape (see column 1 of Table 1). We additionally assessed the extent to which the findings held when allowing for other valid names for the target shapes. Ten adult graduate students who were blind to the hypothesis (M = 28.62 years, SD = 6.33 years, range 25.15 to 46.08 years) assigned each shape-label match generated by children in Experiment 2 no credit, half credit, or full credit. Adults rated all canonical names as full-credit responses. When indicated by consensus agreement (80 percent) non-canonical names were assigned full-credit (e.g., "moon" for crescent, "plus" for cross) or half-credit (e.g., "ball" for circle, "right" for arrow).

Using this coding scheme to represent children's shape knowledge, there remained a positive association between shape frequency in the ChildFreq statistics and children's shape knowledge (r = .82, p = .03). In addition, we still found evidence for age-related changes in shape knowledge: an ANOVA on children's shape knowledge using participant age and shape frequency as predictors indicated main effects of age (F (1, 284) = 27.89, p < .001) and shape frequency (F (1, 284) = 81.48, p < .001). Importantly, we did not find a relationship between children's knowledge of shapes and average performance on TrackIt trials with that target shape (see Figure 7).

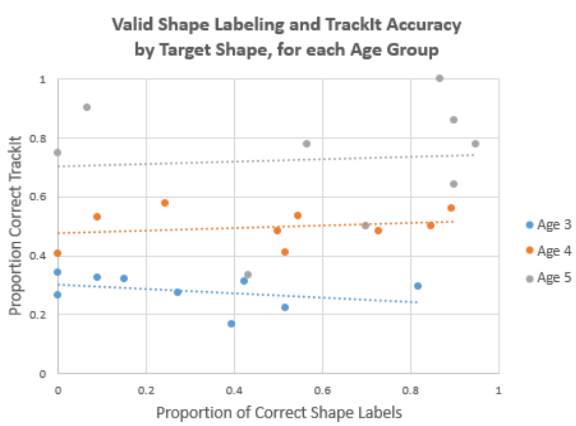

Figure 7: Children's accuracy in shape labeling and on TrackIt trials with that target shape, by age, when allowing for non-canonical labels judged valid by adult participants.

General Discussion

Consistent with prior research, we found effects of age and task difficulty level on performance in the TrackIt task in Experiment 1 (Fisher et al., 2013; Kim et al., 2017). In Experiment 2, we also found that indeed children's shape knowledge was related to age, with older children showing better shape knowledge of shape labels than younger children. We also found that across age, children showed better knowledge of shape labels for more frequently occurring labels. However, across Experiments 1-2 we did not find evidence that shape knowledge or frequency can account for age-related improvement in performance on the TrackIt task. Specifically, we did not find evidence that the frequency of a target shape, as derived from the ChildFreq database, was related to children's performance on TrackIt trials using that target shape. Similarly, we did not find a significant relationship between children's ability to label a target shape and their performance on trials involving that target shape. In contrast, our analyses indicate that children performed similarly across trials regardless of target shape.

These findings help to mitigate concerns that shape knowledge may contribute to children's performance on the TrackIt task, given that knowledge of the different target shapes is likely to emerge at different time points and rates (i.e., if knowledge of the target shape names were a critical aspect of task success, we would expect young children in particular to perform relatively better on trials with high-frequency shapes relative to those with less familiar shapes).

At the same time, that two-year-old children performed at chance overall (on both the main task and the memory check) might indicate that these youngest participants have difficulty encoding any target shape, regardless of its relative frequency. Additional development and school experience might support older children in recognizing the properties of shapes, even if they are not familiar with the canonical names of these shapes (as both the Childes database and children's own performance suggest).

One limitation of the current studies is that our analysis did not account for object color, the other dimension by which target and distractor shapes differed. Children with limited shape knowledge might nonetheless be successful in encoding the target object by using color labels (see Sandhofer & Smith, 1999, for a review of the time course and developmental dependencies of color term learning). We did not test for this hypothesis because currently the TrackIt output records only object shape but not color.

Another limitation of the current set of studies is that some (but not all) of the children providing shape knowledge data in Experiment 2 also completed the TrackIt task in Experiment 1. An alternate design would have allowed us to more directly assess shape knowledge of TrackIt participants, rather than that of a representative peer group.

Conclusions

Across two experiments we obtained no evidence that shape knowledge contributed to children's performance accuracy on the TrackIt task. Accordingly, the results of the present study help to mitigate the concern that shape knowledge may fully or partially account for the age-related changes in performance on the TrackIt task reported in prior studies. Overall, the reported results help to support the previous interpretation of this task as an assessment of selective sustained attention in young children (Erickson et al., 2015; Fisher et al., 2013; Kim et al., 2017).

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