Factor Structure of Attention Capacities Measured With Eye-Tracking Tasks in 18-Month-Old Toddlers

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Marjanneke de Jong[1], Marjolein Verhoeven[1], Ignace T. C. Hooge[1], and Anneloes L. van Baar[1]

Abstract

Objective: Attention capacities are critical for adaptive functioning and development. Reliable assessment measures are needed for the study of attention capacities in early childhood. In the current study, we investigated the factor structure of the Utrecht Tasks of Attention in Toddlers Using Eye-tracking (UTATE) test battery that assesses attention capacities in 18-month-old toddlers with eye-tracking techniques. **Method:** The factor structure of 13 measures of attention capacities, based on four eye-tracking tasks, was investigated in a sample of 95 healthy toddlers (18 months of age) using confirmatory factor analysis. **Results:** Results showed that a three-factor model best fitted the data. The latent constructs reflected an orienting, alerting, and executive attention system. **Conclusion:** This study showed support for a three-factor model of attention capacities in 18-month-old toddlers. Further study is needed to investigate whether the model can also be used with children at risk of attention problems. *(J. of Att. Dis. 2016; 20(3) 230-239)*

Keywords

orienting, alerting, executive attention, eye tracking, factor analysis

Attention capacities are needed already by young children for adaptive functioning and further cognitive as well as socio-emotional development. Problems in attention capacities are related to poor school performance (e.g., Breslau et al., 2009) and lack of social competence (e.g., Andrade, Brodeur, Waschbusch, Stewart, & McGee, 2009). Attention problems are often not detected until school age but might already appear at a younger age (Ruff & Rothbart, 1996). Reliable assessments of attention capacities of young children (younger than 6 years of age) are needed to study early development in attention capacities.

In previous studies, attention is mostly conceptualized as a multi-dimensional construct. Posner and Petersen (1990) described three distinctive attention systems: orienting, alerting, and executive attention. Functioning of the orienting system reflects the capacity to orient to a target, that is, the ability to engage, disengage, and shift attention focus. The alerting system represents the ability to achieve and maintain a state of alertness. The third system, the executive attention system, is defined as goal-directed and planned attention (Mezzacappa, 2004; Posner & Petersen, 1990). These different attention functions can be seen as connected, but independent functions that develop at different moments and show different developmental courses, starting already in infancy (Colombo, 2001).

Few studies empirically investigated the structure of attention capacities in young children. In a study with 6- to 16-year-old children using the Test of Everyday Attention for Children [TEA-Ch], which is based on the attention systems distinguished by Posner and Petersen (1990), support was found for a three-factor model of attention, including selective (i.e., orienting), sustained (i.e., alerting), and executive attention (Manly et al., 2001). The same was found in a study with 5- to 15-year-old Chinese children using the TEA-Ch (Chan, Wang, Ye, Leung, & Mok, 2008). Two studies were found investigating attention structure at preschool age (Breckenridge, Braddick, & Atkinson, 2013; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012). Steele et al. (2012) studied a group of 3- to 6-year old children using computer tasks, where children had to press a button or touch the screen as response, and found support for a two-factor model of attention, including selective/sustained attention and executive attention. Breckenridge et al. (2013) used eight tasks (seven on a computer) with touching or verbal report as

[1]Utrecht University, Netherlands

Corresponding Author:
Marjanneke de Jong, Department of Child and Adolescent Studies, Utrecht University, P.O. Box 80.140, 3508 TC Utrecht, Netherlands.
Email: M.deJong@uu.nl

response types in 3- to 6-year-old children. They found a distinctive structure of attention for 3- to 4.5-year-old versus 4.5- to 6-year-old children. In 3- to 4.5-year-old children, a two-factor model showed the best fit to the data including selective/executive attention and sustained attention. For 4.5- to 6-year-old children, a three-factor model including selective, sustained, and executive attention best fitted the data (Breckenridge et al., 2013). Steele et al. (2012) suggested that attention might be less differentiated in young children. No studies were found investigating the structure of attention in children below 3 years of age.

Next to verbal responses and touching behavior, looking behavior might be used as an indicator of attention capacities in young children. Eye-tracking techniques can be used to accurately assess looking behavior. This technique has been successfully used to assess attention capacities in infants below 12 months of age (e.g., Butcher, Kalverboer, & Geuze, 2000; Hunnius, Geuze, & Van Geert, 2006). In toddlers, eye tracking has been used to study behaviors such as anticipatory looks and goal-directed gaze shifts (e.g., Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Paulus, Hunnius, & Bekkering, 2011) and preferential looking behavior of toddlers with Autism Spectrum Disorder (e.g., Jones, Carr, & Klin, 2008). However, as yet, little is known about the feasibility and potential of eye-tracking technology to assess attention capacities in toddlers.

Based on the three attention systems described by Posner and Petersen (1990), a test battery of four eye-tracker tasks (the Utrecht Tasks of Attention in Toddlers Using Eye-tracking [UTATE]) was designed and described in a pilot study (De Jong, Verhoeven, Hooge, & Van Baar, 2013). Testing the UTATE in 16 children showed that the test battery is feasible for use with toddlers and can result in data of good quality. In the current study, we will examine whether the supposedly underlying attention systems indeed are being measured with these tasks in a larger sample ($n = 95$) of 18-month-old toddlers.

Based on studies of attention in young children, 4 models were investigated in the current study: (a) a one-factor model, to study whether the attention capacities form a unitary construct, (b) a two-factor model as found in the study by Steele et al. (2012) including orienting/alerting and executive attention, (c) a two-factor model including orienting/executive attention and alerting based on findings of Breckenridge et al. (2013), and (d) a three-factor model including orienting, alerting, and executive attention, based on Posner and Petersen's (1990) theory.

Method

Participants

Parents and children were recruited via the hospital where the infants were born. Healthy term children (gestational age 37-42 weeks) born between March 1, 2010, and April 1, 2011, were eligible for the study. Exclusion criteria were dysmaturity (birth weight below 10th percentile), multiple birth, admission to the Neonatal Intensive Care Unit, severe congenital malformations, antenatal alcohol or drug abuse by mother, and chronic antenatal use of psychofarmaca by mother. Participants were 98 Dutch 18-month-old toddlers, $M = 17.54$ months, $SD = 0.50$, of whom 43 (43.9%) were boys.

The medical ethical committee of the Utrecht Medical Center approved this study as part of a larger study on attention capacities of young children. Informed consent was given by the parents. The children received a present after the visit and parents received refund of travel expenses.

Measures

Four eye-tracker tasks were used to measure the attention capacities of the toddlers, the UTATE: (a) disengagement task, (b) face task, (c) alerting task, and (d) delayed response task (De Jong et al., 2013). In the *disengagement task*, a visual stimulus was first presented at the center of the screen, and after 2 s a second stimulus appeared at the left or the right side of the central stimulus. This task consisted of 20 trials. In the *face task*, first two identical pictures of child faces were shown, and after 8.5 s, one of the pictures changed into a new picture and stayed on the screen together with the previously shown picture for 8 s. The face task consisted of eight trials. In the *alerting task*, a visual stimulus was presented on the screen, in half of the trials preceded by a signaling sound. The alerting task consisted of 32 trials. In the *delayed response task*, a dog was hiding in one out of two doghouses and after a certain delay (i.e., varying from 0-10 s), the child was asked to search for the dog. This task consisted of 18 trials in which the delay increased from 0 to 10 s with steps of 2 s after three consecutive trials. Timing and stimulus size are presented in Figure 1. The tasks are described in more detail elsewhere (De Jong et al., 2013). Definitions of the variables observed in these four tasks are presented in Table 1 and described below per attention system.

Orienting system. The capacities to orient on a target concern the abilities to engage, disengage, and shift attention focus from a target (Posner & Petersen, 1990). Six variables were supposed to reflect functioning of the orienting system: *mean dwell time* and *transition rate* from the disengagement and face task, and *proportion of correct refixations* and *latency* from the disengagement task. Mean dwell time in the disengagement task includes dwells at the central and the peripheral stimulus.

Alerting system. The abilities to achieve and maintain a state of alertness form the alerting system (Posner & Petersen, 1990). Five variables were supposed to reflect functioning

Table 1. Definitions of the Observed Variables From the Eye-Tracker Tasks.

Outcome measure	Task	Definition
Orienting system		
Mean dwell time	DIS, FACE	Average length of the dwells. A dwell is the length of "one visit in an area of interest [AOI] from entry to exit" (Holmqvist et al., 2011)
Transition rate	DIS, FACE	The number of transitions (i.e., "movement from one AOI to another," Holmqvist et al., 2011) divided by the total dwell time.
Proportion of correct refixations	DIS	A correct refixation indicates that the participant refixated from the central stimulus to the new stimulus after the new stimulus is presented. The proportion of correct refixations is the number of correct refixations divided by the total number of trials in which the child looked at the central stimulus when the new stimulus appeared.
Latency	DIS	The average time between appearance of the new stimulus and fixation on the new stimulus in trials in which the participant correctly refixated.
Alerting system		
Total dwell time	DIS, FACE, AL, DR	Sum of the length of all dwells. A dwell is the length of "one visit in an area of interest from entry to exit" (Holmqvist et al., 2011)
Latency difference	AL	Difference between latencies in the trials in which a signal preceded the appearance of the stimulus (i.e., signal trials) and the trials in which the stimulus appeared without signal (i.e., no-signal trials).
Executive attention system		
Correct searches	DR	The number of trials in which the child looked at the correct doghouse directly in response to the voice over asking where to find the dog.
Mean delay	DR	The mean delay between hiding and the instruction to seek the dog in the trials in which the child correctly searched for the dog.

Note. DIS = disengagement task; FACE = face task; AL = alerting task; DR = delayed response task.

of the alerting system: *total dwell time* from all four tasks, and the *difference in latencies* in the alerting task.

Executive attention system. The executive attention system is defined as goal-directed, planned attention and the ability to inhibit behavior (Posner & Petersen, 1990). Two variables from the delayed response task were supposed to reflect functioning of the executive attention system: the number of *correct searches* and the *mean delay*.

Apparatus

The Tobii T60 Eye Tracker with an integrated 17-inch TFT screen with a resolution of 1280 by 1024 pixels was used (Tobii Technology, Stockholm, Sweden). The Tobii T60 measures corneal reflection at a frequency of 60 Hz with an accuracy of 0.5°, and it has a spatial resolution of 0.2°. Using a white background, the precision (i.e., amount of root mean square [RMS] noise) is 0.50° (Tobii, 2011). The head box, or freedom of head movements, is 44 × 22 × 30 cm. Head movements are compensated by the eye tracker, which results in a temporary accuracy error of 0.2°. When the eye tracker loses track of the child's eyes (e.g., fast head movements of more than 25cm/s), it recovers in 300 ms. E-prime 2.0 software (Psychology Software Tools, Pittsburgh, Pennsylvania) was used to present the stimuli on the screen.

Procedure

Children were seated in a car seat at a distance of approximately 65 cm from the eye tracker. In line with Hunnius and Bekkering (2010), a 9-point calibration was used in which a movie clip of a bouncing ball accompanied by sound was presented at nine different points on the screen (i.e., left, middle, and right at the top, center, and bottom of the screen). Calibration was accepted when the child looked at seven or more of the calibration points. Otherwise, several points were recalibrated. After calibration, the four tasks were presented in the following fixed order: (a) disengagement task, (b) face task, (c) alerting task, and (d) delayed response task. The face of the children was also recorded with a video camera behind the eye tracker to be able to check the behavior of the child during the procedure. The whole procedure took about 18 min to complete.

Data Analysis

Matlab 7.11 (The MathWorks, Inc.) was used to analyze gaze data. Fixation detection was done by a self-written Matlab program (I.H.) that marked fixations by an adaptive velocity threshold method. We used an adaptive velocity threshold method to detect fixations because the amount of noise may vary a lot in eye-tracking data (especially with low frequency trackers such as the Tobii T60 and with

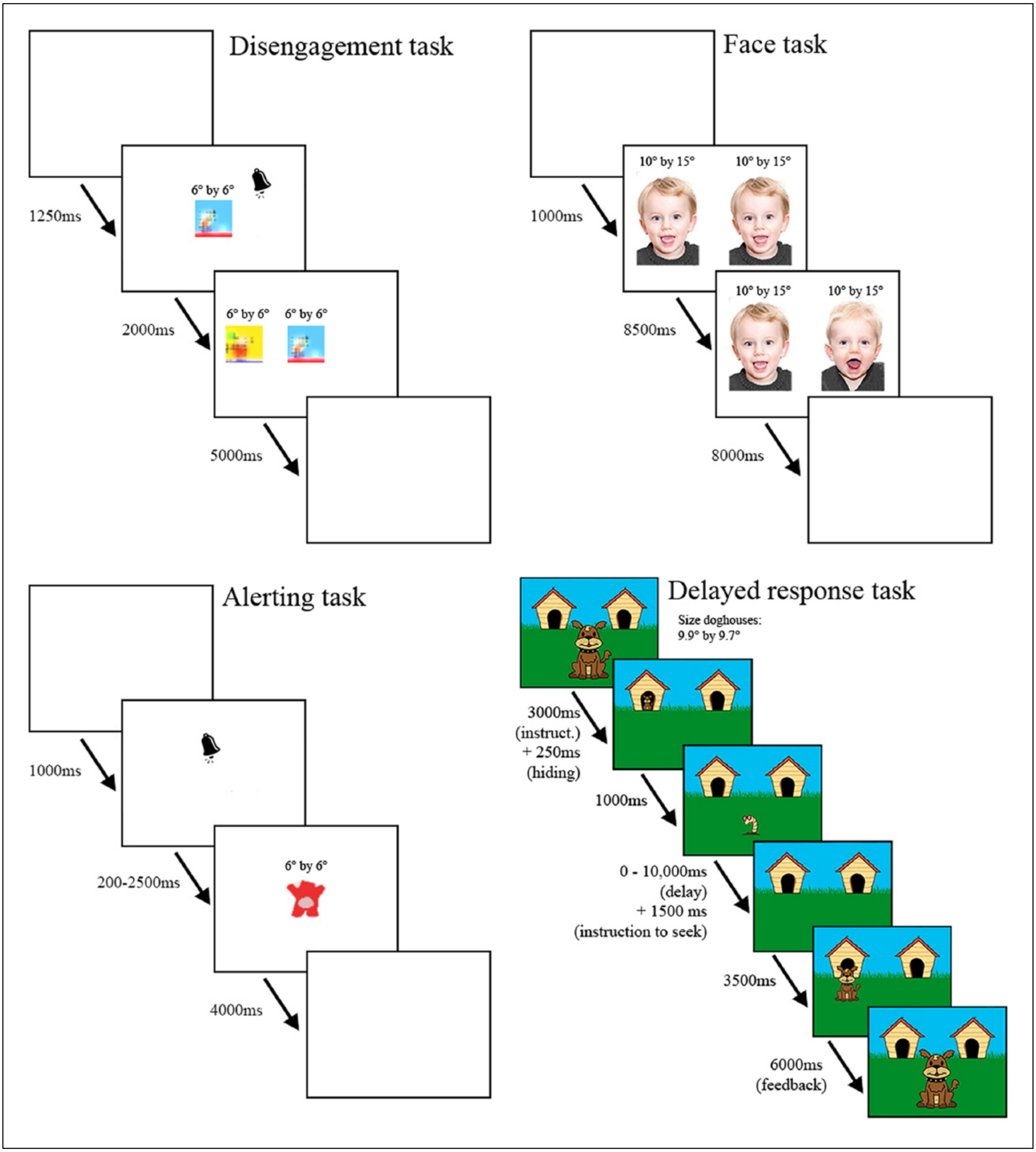

Figure 1. Visualization of timing and size of the stimuli in the different tasks.

non-grown-up participants). Many modern saccade and fixation detection methods are partly or fully adaptive to the noise in the data (Nyström & Holmqvist, 2010; Smeets & Hooge, 2003). Velocities were obtained by fitting a parabola through three subsequent data points. We used the derivative of this fitted parabola to estimate the value of the velocity of the second (center) data point. This procedure was repeated for all data points (except the first and the last). In the present analyses, everything that is not a saccade is called a fixation. To remove the saccades from the signal, we calculated average and standard deviation from the absolute velocity signal. All data points having absolute velocities higher than the average velocity plus 3 times the standard deviation were removed. This procedure was repeated until the velocity threshold converged to a constant value or the number of repetitions reached 50. Then we removed fixations having durations shorter than 60 ms from the analysis. The value of 60 ms was chosen because it is equal to three data samples. When a saccade was removed, the preceding and succeeding fixations were added together. Data of the children were included when they looked at the stimuli at least once during a task, and thereby providing data on the variables of this task.

To investigate the factor structure of the attention measures, confirmatory factor analysis with maximum likelihood was conducted using the Lavaan package (Rosseel, 2012) in the R system for statistical computing (R Core Team, 2012). Z scores were used instead of raw scores because of large differences in scaling and variances between the variables. The observed variables were allowed to load on only one latent factor. Latent factors were allowed to correlate. As method effects of the different tasks could occur in our data, a correlated trait–correlated uniqueness model (CTCU; Marsh, 1989) was investigated. In this model, error covariances were freely estimated between observed variables from the same task, except for "correct searches" and "mean delay" from the delayed response task. These two variables are indicators of the latent variable "executive attention"; therefore, correlated error is already captured in the latent variable. This results in a model with 16 estimated error covariances.

To assess model fit, the chi-square test statistic (χ^2), the root mean square error of approximation (RMSEA), the standardized root mean squared residual (SRMR), the comparative fit index (CFI), the Tucker–Lewis index (TLI) and the Akaike Information Criterion (AIC) were used. The chi-square test measures equality between the population covariance matrix and the model-implied covariance matrix (Schermelleh-Engel, Moosbrugger, & Müller, 2003). RMSEA measures the approximate fit of the model in the population instead of exact fit (Schermelleh-Engel et al., 2003). SRMR is a measure of the difference between observed and model-implied covariances (Schermelleh-Engel et al., 2003). CFI is a comparison between the fit of the target model and a very restricted baseline model (Schermelleh-Engel et al., 2003). TLI measures the proportion of improvement in fit of the target model compared with the baseline model, corrected for degrees of freedom (Schermelleh-Engel et al., 2003). AIC is a descriptive measure that will be used to compare results of different models. The model with the lowest AIC value can be seen as the best fitting model (Schermelleh-Engel et al., 2003). A model was considered to show a good fit based on the following criteria: p value of chi-square > .05, RMSEA < .06, SRMR < .08, CFI > .95, TLI > .95 (Hu & Bentler, 1999).

Results

All participants ($N = 98$) produced data on at least one of the variables. Three participants produced no data on one or more of the variables, due to technical problems. These participants were excluded from further analyses. The other children produced data on all variables; therefore, the following analyses included data of 95 children. Descriptive statistics of the 13 variables are presented in Table 2. Next to the range, also the 25% to 75% range is presented in Table 2 to show the variation in scores without the more extreme scores as well.

Correlations between the observed variables are presented in Table 3. Large variation is seen in the correlations between the variables. Of the 78 correlations, 32 were found to be significant with 4 expected by chance. Of these correlations, 21 were moderate to strong (i.e., >.30), and these were found to be between variable pairs of the same task or between variable pairs of the same attention system.

Fit indices of the four tested models are shown in Table 4. The one- and two-factor models showed poor fit. The three-factor model showed good fit: chi-square = 62.46, *ns*, RMSEA = .06, SRMR = .08, CFI = .97, and TLI = .95. In addition, the AIC was the lowest in the three-factor model, indicating that this model fitted the data best.

Factor loadings of the four models are presented in Table 5. The final (three-factor) model is presented in Figure 2. Factor loadings of the orienting system varied between .01 and .70. The orienting system is best reflected in *mean dwell times* and *transition rates* in the disengagement and face task. Two-factor loadings were not significant and below .30: *latency* and *proportion correct refixations* in the disengagement task. Factor loadings of the alerting system varied between .05 and .83. One-factor loading was not significant and below .30: *latency difference* in the alerting task. The alerting system is best reflected in *total dwell time* in all four tasks. Factor loadings of the executive attention system were significant and .83 for number of *correct searches* and .58 for *mean delay.* As some of the factor loadings were not significant, we also explored whether a model without these variables would fit the data. This model also showed good fit: chi-square = 36.66, $p = .047$, RMSEA = .07, SRMR = .07, CFI = .98, and TLI = .96.

Correlations between the latent variables were .72, $p < .001$, between orienting and alerting, .50, $p < .001$, between alerting and executive attention, and .26, $p = .032$, between orienting and executive attention. These correlations not only indicated some overlap in measurement of different attention systems but also showed that the three factors reflect different aspects of the children's functioning.

Discussion

The UTATE was found to measure functioning of three attention systems in 18-month-old toddlers, because the three-factor

Table 2. Descriptive Statistics of the Outcome Variables.

Variable	*M* (*SD*)	Range	25%-75% range
Disengagement task			
Number of trials[a]	17.65 (2.70)	6-20	16-20
Number of valid trials[b]	14.25 (3.49)	4-20	12-17
Mean dwell time	1,444 (325)	952-2,520	1,238-1,630
Latency	610 (226)	347-1,517	455-702
Proportion correct refixations	0.97 (0.05)	0.76-1.00	1.00-1.00
Transition rate	0.46 (0.12)	0.22-0.79	0.39-0.55
Total dwell time	92,054 (21,377)	23,152-125,981	78,535-107,523
Face task			
Number of trials[a]	7.07 (1.24)	3-8	7-8
Mean dwell time	1,244 (266)	689-2,009	1,058-1,424
Transition rate	0.64 (0.15)	0.39-1.13	0.52-0.73
Total dwell time	79,132 (20,397)	14,887-113,896	68,291-95,613
Alerting task			
Number of trials[a]	21.55 (6.89)	5-32	17-27
Latency difference	127 (271)	−432-1,438	−26-282
Total dwell time	55,773 (22,223)	7,966-111,283	38,421-73,201
Delayed response task			
Number of trials[c]	14.82 (4.30)	0[d]-18	14-18
Correct searches	9.45 (3.51)	0-18	7-12
Mean delay	5.35 (1.56)	0-9	4.67-6.25
Total dwell time	76,748 (29,477)	300-140,866	62,036-98,404

[a]Number of trials in which the children looked at the stimuli.
[b]Number of trials in which the children looked at the central stimulus when the peripheral stimulus was presented.
[c]Number of trials in which the children looked at one of the doghouses after they were asked to search for the dog.
[d]This value is 0 for one child, because this child looked at the stimuli for 300 ms during another moment in a trial than the moment on which "number of trials" is based (see [c]).

Table 3. Correlations Between the Outcome Measures From the Eye-Tracker Tasks.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Orienting system													
1. DIS mean dwell time	1												
2. DIS latency	.29**	1											
3. DIS proportion correct	−.23*	−.35**	1										
4. DIS transition rate	−.87**	−.39**	.24*	1									
5. FACE mean dwell time	.49**	.21*	−.07	−.42**	1								
6. FACE transition rate	−.37**	−.22*	.10	.40**	−.87**	1							
Alerting system													
7. DIS total dwell time	.61**	.07	.03	−.42**	.19	−.02	1						
8. FACE total dwell time	.36**	.11	−.04	−.24*	.59**	−.34**	.41**	1					
9. AL total dwell time	.26*	−.04	.16	−.15	.29**	−.11	.43**	.52**	1				
10. AL difference in latency	−.14	−.10	.06	.29**	.01	−.06	−.04	.08	.02	1			
11. DR total dwell time	.10	.06	−.01	−.04	.13	−.10	.17	.31**	.25*	−.15	1		
Executive attention system													
12. DR correct searches	.04	.01	−.00	.03	.07	.03	.16	.38**	.20	−.12	.70**	1	
13. DR mean delay	.17	.00	−.09	−.15	.14	−.15	.16	.27	.16	−.10	.45**	.50**	1

Note. DIS = disengagement task, FACE = face task, AL = alerting task, DR = delayed response task.
**p* < .05. ***p* <.01.

Table 4. Goodness-of-Fit Indices of the Different Models.

Model	χ^2	*df*	RMSEA	SRMR	CFI	TLI	AIC
Model 1	101.04**	49	.11	.11	.91	.86	3,018.13
Model 2	81.43**	48	.09	.10	.94	.91	3,000.51
Model 3	98.66**	48	.11	.11	.91	.86	3,017.74
Model 4	62.64	46	.06	.08	.97	.95	2,985.73

Note. Model 1 = 1-factor model; Model 2 = 2-factor model including orienting/alerting and executive attention; Model 3 = 2-factor model including orienting/executive attention and alerting; Model 4 = 3-factor model including orienting, alerting and executive attention. RMSEA = root mean square error of approximation; SRMR = standardized root mean squared residual; CFI = comparative fit index; TLI = Tucker–Lewis index; AIC = Akaike Information Criterion.
*$p < .05$. **$p < .01$.

Table 5. Standardized Factor Loadings of the Observed Variables of the Four Tested Models.

		Model 2		Model 3		Model 4		
	Model 1	O/A	E	O/E	A	O	A	E
1. DIS mean dwell time	.38**	.38**	—	.56**	—	.58**	—	—
2. DIS latency	.05	.04	—	.09	—	.15	—	—
3. DIS proportion of correct refixations	.03	.05	—	.03	—	.01	—	—
4. DIS transition rate	−.20	−.19	—	−.34**	—	−.39**	—	—
5. FACE mean dwell time	.40**	.41**	—	.58**	—	.70**	—	—
6. FACE transition rate	−.13	−.11	—	−.29*	—	−.43**	—	—
7. DIS total dwell time	.54**	.55**	—	—	.60**	—	.53**	—
8. FACE total dwell time	.79**	.80**	—	—	.78**	—	.83**	—
9. AL total dwell time	.64**	.64**	—	—	.68**	—	.64**	—
10. AL latency difference	.06	.10	—	—	.07	—	.05	—
11. DR total dwell time	.38**	.33**	—	—	.25**	—	.36**	—
12. DR correct searches	.45**	—	.89**	.26*	—	—	—	.83**
13. DR mean delay	.33**	—	.55**	.23	—	—	—	.58**

Note. Model 1 = 1-factor model; Model 2 = 2-factor model: orienting/alerting and executive attention; Model 3 = 2-factor model: orienting/executive attention and alerting; Model 4 = 3-factor model; O = orienting system; A = alerting system; E = executive attention system; DIS = disengagement task; FACE = face task; AL = alerting task; DR = delayed response task.
*$p < .05$. **$p < .01$.

model best fitted the data. This result supported the theory of Posner and Petersen (1990) that distinguished three attention systems. The results are also in accordance with studies investigating the factor structure of attention in school-aged children (Breckenridge et al., 2013; Chan et al., 2008; Manly et al., 2001). However, our results on a sample of toddlers were in contrast to the findings in preschool-aged children, where a two-factor model showed the best fit (Breckenridge et al., 2013; Steele et al., 2012). Steele et al. (2012) suggested that attention might be less differentiated in younger children, which was not supported by our findings on even younger children. These contrasting findings might be due to differences in the methods used. While we used eye-tracking measures relying on eye movements and looking behavior, other studies used tasks where children had to press a button or touch the screen (Breckenridge et al., 2013; Steele et al., 2012) or had to verbally report (Breckenridge et al., 2013) as response. It might be that such responses provide a less differentiated representation of attention skills as they require additional maneuvers in which subtle differences between attention capacities might be lost.

Although the fit of the three-factor model was good, some of the factor loadings were low. Latency and proportion of correct refixations from the disengagement task did not significantly load on the orienting system. Proportion of correct refixations did not sufficiently differentiate between the children at 18 months of age, because on average, the children correctly refixated in 97% of the trials and 76% of the children correctly refixated in all trials. This lack of variation between the children might explain why the proportion of correct refixations did not load significantly on the orienting system. Latency did not load on the orienting system, which was surprising as it was related to mean dwell time and transition rate in the disengagement and face task (correlations between .21 and .39, see Table 3). Perhaps the way it was measured is important, as mean dwell time and transition rate were based on more than one measurement per trial

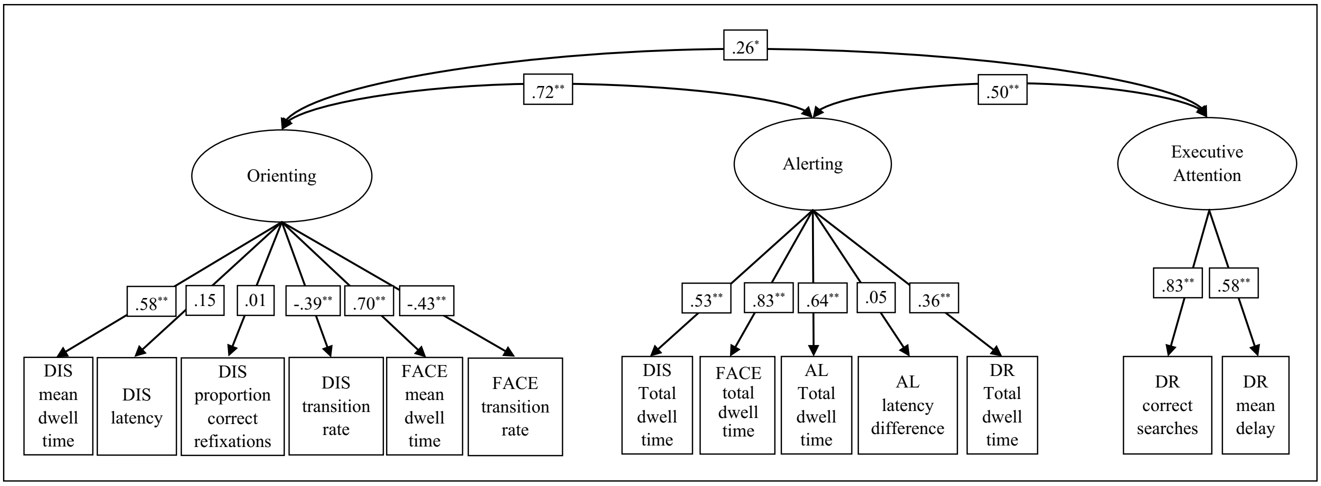

Figure 2. Three-factor model.
Note. DIS = disengagement task; FACE = face task; AL = alerting task; DR = delayed response task.
**p* < .05. ***p* <.01.

(i.e., a child could have more than one dwell and transition within a trial), whereas latency was not. Latency was based on only one measure per trial, as it reflected the time between appearance of the new stimulus and the first look at that new stimulus. Therefore, it may be that latency reflected something else than a generally reflexive orienting process at this age, for instance, a more self-generated shift in attention to a new stimulus. Further research is needed to investigate how latency is related to other measures that reflect age-related behavior, such as developmental level in cognitive skills.

With respect to the alerting system, latency difference, a variable from the alerting task, did not load significantly on the latent construct. The alerting system is supposed to be responsible for the ability to achieve and maintain a state of alertness (Posner & Petersen, 1990). Four out of the five variables of the alerting system were measures of sustained attention, while latency difference was mainly a measure of the ability to achieve a state of alertness. It might be that at toddler age, the ability to achieve a state of alertness differs from the ability to maintain it. This might explain the non-significant loading of latency difference. An extra analysis with the variables with non-significant factor loadings excluded also resulted in a model with good fit indices. Further study, for instance, concerning measurement invariance when comparing groups at risk of attention problems, could provide information about which model proves to be the most robust and useful in answering research questions on attention development.

A strong correlation was found between the orienting and alerting systems, a moderate effect was seen for the relationship between the alerting and executive attention systems, and a weak relationship was found for the orienting and executive attention systems. These relationships showed support for the findings and ideas of Colombo (2001) that attention systems may show different developmental courses, with orienting and alerting, that showed the strongest relationship in our sample of toddlers, developing at an earlier age than executive attention. All correlations were positive, indicating that a higher score on one attention system is related to a higher score on another attention system.

With respect to orienting, previous studies with young infants considered shorter mean dwell times, higher transition rates, higher proportions of correct refixations, and shorter latencies to be indicative of better functioning of the orienting system (Colombo, 2002; Rose, Feldman, & Jankowski, 2002). Our study with toddlers, however, showed opposite results: A higher score on orienting in our model (Figure 2) reflected longer mean dwell times and lower transition rates. Age differences between the samples in different studies could be important in explaining differences in results. The studies of Colombo (2002) and Rose et al. (2002) concerned infants below 1 year of age. It might be that in toddlers, longer mean dwell times and fewer transitions are indicative of better functioning of the orienting system and such behaviors thus have a different meaning than in infancy. In addition, short looking can be interpreted in several different ways, as it might reflect both efficient information processing, or in contrast, a short attention span (Atkinson & Braddick, 2012). Further research is currently conducted to investigate the functioning of the attention systems in relation to other measures of attention capacities, such as questionnaires filled out by parents and observations of child behavior during parent–child interactions.

Strength of this study was that the relatively objective eye-tracking measures were used to assess attention capacities. A limitation of the study was that the sample size is still rather small. Further research should investigate whether this model also fits data of larger samples. An important characteristic of this study is that a non-clinical sample was used. Further study is necessary to see whether the model also can be applied with children at risk of attention problems, such as preterm born children (e.g., van Baar, Vermaas, Knots, de Kleine, & Soons, 2009).

In conclusion, this study showed support in a sample of 18-month-old toddlers for a three-factor model of attention capacities using orienting, alerting, and executive attention as latent constructs, reflected in four eye-tracker tasks. The study of differences in attention capacities, as measured with the four eye-tracker tasks, for example, between groups of toddlers at risk of attention problems or not, and the study of the relationships of attention capacities with other developmental outcomes, can now be improved, as the 13 observed eye-tracking variables can reliably be reduced to three latent constructs.

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Author Biographies

Marjanneke de Jong is a PhD candidate at the Department of Child and Adolescent Studies at Utrecht University. Her research interests include the role of perinatal risk factors, such as prematurity, and attention development.

Marjolein Verhoeven, PhD, is an assistant professor at the Department of Child and Adolescent Studies at Utrecht University. Her research interests include the role of perinatal risk factors, parenting, and attention development.

Ignace T. C. Hooge, PhD, is an associate professor at the Department of Experimental Psychology at Utrecht University. His research interests include eye tracking methodology, visual perception and saccadic eye movements.

Anneloes L. van Baar is a professor at the Department of Child and Adolescent Studies at Utrecht University. Her research interests include the role of perinatal risk factors, such as prematurity, assessment instruments, and attention development.