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Brief Report

Individual differences in visual attention and self-regulation: A multimethod longitudinal study from infancy to toddlerhood

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A B S T R A C T

Given the importance of self-regulation for a broad range of developmental outcomes, identifying reliable precursors of self-regulation early in development is important for early prevention of developmental problems. The aim of this study was to examine whether three visual attention measures (fixation duration, variation in fixation duration, and disengagement) in infancy (9.10–11.43 months of age) predicted effortful control and compliance in toddlerhood (26.71–31.80 months). The sample consisted of 74 children (50% boys). In infancy, two eye-tracking tasks were conducted: a visual search task to assess fixation duration and variation in fixation duration ($n = 58$) and the gap–overlap task to assess disengagement ($n = 49$). In toddlerhood, children's effortful control ($n = 65$) and compliance ($n = 65$) were assessed by parent reports and observed during a delay of gratification task and a cleanup session together with the parents, respectively. Using full information maximum likelihood to account for missing data, multiple regression analyses revealed that, when all three measures of visual attention were taken into account, longer fixations and less variation in fixation duration in infancy predicted better effortful control. Disengagement did not predict effortful control. Compliance in toddlerhood was not predicted by any of the visual

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attention measures. These findings may indicate that visual attentional measures in infancy predict relatively independent forms of self-regulation in toddlerhood. Future studies are necessary to elucidate the mechanisms that underlie the association between (variation in) fixation duration in infancy and effortful control in toddlerhood.

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Introduction

Self-regulation, which is defined as the ability to automatically or deliberately modulate affect, behavior, and cognition (Karoly, 1993), plays an important role in human development. For instance, higher levels of self-regulation relate to better school performance (Bull, Espy, & Wiebe, 2008) and less problem behavior (Olson, Sameroff, Kerr, Lopez, & Wellman, 2005). Knowledge of early individual differences that may predict later self-regulation is important for early prevention of developmental problems. However, studies on early antecedents of self-regulation are relatively scarce. In this study, we focused on antecedents of emerging self-regulation in toddlerhood. Toddlerhood is a transitional phase during which the ability to inhibit dominant responses develops, and external regulation is still required (Kopp, 1982). This is exemplified by compliance, which indicates toddlers' ability to display desirable behavior in response to others. Compliance is related to effortful control, which refers to individuals' ability to inhibit prepotent behaviors and perform less salient behaviors, detect errors, and engage in planning (Rothbart, Sheese, Rueda, & Posner, 2011). Although compliance and effortful control are related, effortful control is more independent compared with compliance because the latter, per definition, occurs in response to others.

Various theoretical frameworks argue that the development of self-regulation builds on simpler cognitive skills, in particular visual attention (e.g., Kochanska, Murray, & Harlan, 2000; Rothbart et al., 2011). Visual attention refers to a set of cognitive operations by which the selection of relevant visual information, and the exclusion of irrelevant visual information, occurs. Posner, Rothbart, and colleagues proposed that attentional processes involve three neural networks that are closely related to self-regulation. The alerting network is involved in achieving and maintaining attention, the orienting network is involved in selecting input, and control over these networks is executed through the executive attention network (Posner, Rothbart, Sheese, & Voelker, 2012). Over development, the relative importance of these networks for self-regulation gradually shifts, with the orienting network being most important in infancy and the executive attention network taking over at around 3 or 4 years of age (Posner et al., 2012). This allows children to progressively exert more independent control.

In line with the notion that visual attention is an antecedent of self-regulation, relatively coarse attention measures indeed predict self-regulation later in development (see Hendry, Jones, & Charman, 2016, for a review). These measures generally capture a variety of processes that may be difficult to disentangle. For instance, habituation studies typically demonstrate that shorter dwell times in infancy, measured using video cameras, predict better self-regulation later in development (e.g., Cuevas & Bell, 2014; cf. Papageorgiou, Farroni, Johnson, Smith, & Ronald, 2015). These studies build on the notion that shorter lasting orienting responses reflect faster processing speed. Yet, these orienting responses relate to various attentional processes, including the ability to disengage attention (Colombo & Mitchell, 2009). A more detailed examination of attentional processes implicated in the development of self-regulation may be achieved with eye-tracking measures. In this study, we focused on the predictive value of three microtemporal measures of visual attention: fixation duration, variation in fixation duration, and disengagement.

In eye-tracking studies, visual attention is generally characterized in terms of fixations and saccades. During fixations, the eyes are relatively stable with respect to the world, which allows for inspection of different areas of the visual scene. Because only a small part of the retina, the fovea, allows for high-acuity vision, saccadic movements are made to allow light to fall on the fovea (Holmqvist et al., 2011). The duration of a fixation is often conceptualized as an indicator of the time needed to process the visual information available at the point of fixation (Nuthmann, Smith, Engbert, & Henderson, 2010). Individual differences in fixation duration are relatively stable across various viewing materials and show good test–retest reliability in infancy (Hessels, Hooge, & Kemner, 2016; Wass & Smith, 2014). Although a cross-sectional study indicated that fixation durations were unrelated to concurrent cognitive control in infancy (Wass & Smith, 2014), the only longitudinal study found that longer fixations in infancy predicted better parent-reported effortful control in children between 19 and 58 months old (Papageorgiou et al., 2014). Papageorgiou et al. (2014) suggested that longer fixations indicate better executive attention because there is an enduring conflict between maintaining fixation and disengaging attention.

Variation in fixation duration is another relevant measure of visual attention in relation to self-regulation. In adults, saccades are made at a relatively constant rate independent of the current visual input. Yet, there is some moment-to-moment monitoring that determines the duration of a fixation (Henderson & Smith, 2009). It is possible that higher within-person variation of fixation duration indicates an enhanced ability to adjust attention duration when this is desired, for instance, because of increased interest (Wass & Smith, 2014). Conversely, individual distributions of fixation durations become narrower throughout the first year of life (Hunnius & Geuze, 2004), indicating that less variation may be an indicator of cognitive maturity. Diminished variation in fixation duration when watching dynamic (but not static) stimuli in infancy relates to better concurrent cognitive control (Wass & Smith, 2014). No studies so far have examined whether variation in fixation duration in infancy predicts self-regulation.

Next to fixations, disengagement of attention (related to the orienting network) is a necessary requirement to attend to parts of the environment and for preventing or stopping overstimulation. Disengagement plays an important role in early state regulation (Rothbart et al., 2011). For instance, attentional disengagement is found to be an effective strategy for lowering negative affect in infancy (Stifter & Braungart, 1995). Prolonged disengagement is also found in infants at risk for autism, a finding that may be related to the deficits in self-regulation that have been reported for these children (Elsabbagh et al., 2013; Gliga, Jones, Bedford, Charman, & Johnson, 2014). Moreover, two studies directly examined associations between disengagement and effortful control, or its forerunners. First, infants at 4 and 6 months of age who disengaged quicker were less distressed but not easier to soothe (McConnell & Bryson, 2005). The second study found a negative association between disengagement latencies and parent-reported orienting/regulation at 12 months of age but found no predictive association between disengagement latencies at 12 months and observed and parent-reported effortful control at 36 months (Nakagawa & Sukigara, 2013).

The aim of this longitudinal study was to simultaneously examine the predictive value of fixation duration, variation in fixation duration, and disengagement in infancy (9–11 months of age) for effortful control and compliance in toddlerhood (26–32 months). We hypothesized that longer fixation duration would predict better effortful control and compliance, whereas our analyses regarding the variation in fixation duration were exploratory. We also hypothesized that faster disengagement would predict better effortful control and compliance in toddlerhood.

Method

Participants

A total of 80 infants between 9 and 11 months of age and one of their parents were recruited through local municipalities within the province of Utrecht, the Netherlands. Infants were excluded if they were born before 37 weeks of pregnancy, had a significant uncorrected hearing or vision impairment, or had a significant developmental delay or condition. Of this sample, 65 children and one of their parents also participated during a second wave in toddlerhood.

The final sample consisted of 74 children who provided usable data during at least one wave. Infants (50% boys) ranged between 9.10 and 11.43 months of age (M = 10.04, SD = 0.38) during the first wave in infancy and between 26.71 and 31.80 months (M = 28.50, SD = 1.20) during the second wave in toddlerhood. Parents accompanying infants during the first wave were predominantly higher educated (77% reported having at least a college degree).

Apparatus

Infants' eye movements were recorded with a Tobii TX300 eye tracker (Tobii Technology, Stockholm, Sweden) running at 300 Hz. Stimuli were presented on an integrated 23-inch monitor at a resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. The eye tracker communicated with MATLAB (Version R2013a; The MathWorks, Natick, MA, USA) and the PsychToolbox (Version 3.0.11; Brainard, 1997) via the Tobii SDK and ran on a MacBook Pro (OS X 10.9).

Procedure

During both waves, parents provided written informed consent before participation and received a small financial compensation. Children received a small gift.

Wave 1

The first wave was part of a larger project aimed at studying test–retest reliability of infant measures (YOUth cohort; Hessels, Andersson, Hooge, Nyström, & Kemner, 2015). The study involved 2 testing days in a lab center within 2 weeks (M_{weeks} = 1.07, SD = 0.38; 2 children were tested within 3 weeks). The same procedure was followed on both testing days. A testing day lasted approximately 5 h, including breaks and approximately 90 min of assessments. Electroencephalography, eye-tracking tasks, parent–child interaction tasks, and a developmental assessment were administered. The protocol was approved by the ethical committee of the University Medical Center Utrecht.

For the eye-tracking tasks, familiarization and positioning of the infant was done as described in Hessels et al. (2016). Briefly, each infant was strapped into a baby chair placed on the parent's lap in front of the eye tracker. The eyes of the infant were at distance of 65 cm from the eye tracker and were at the same height as the center of the screen. The operator monitored the infant with a webcam and presented sounds or videos with sound in the center of the screen to keep the infant's attention on the screen during the task. If the infant was not attending to the screen, the operator could present sounds or videos with sound in the center of the screen to attract the infant's attention.

Wave 2

Two examiners visited toddlers and parents at their homes. Three tasks for children, questionnaires for parents, and parent–child interaction tasks were administered. This visit lasted approximately 90 min, allowing sufficient time for breaks. The protocol was approved by the ethical committee of the Faculty of Social and Behavioral Sciences of Utrecht University.

Measures

Fixation duration and variation in fixation duration

A total of 24 visual search displays were presented, each containing two rows of 14 lines (Hessels et al., 2016). These lines were jittered between −1.68° and 1.68° in a horizontal direction and between −6.38° and 6.38° in a vertical direction. All lines were vertically aligned except for one divergent line that was tilted 30°, 60°, or 90° clockwise. The divergent line appeared once on eight different locations in all three angles. Every trial lasted until the infant fixated on the divergent line within a range of 1.4° for at least 100 ms or until 4 s had passed. Calibration occurred at the start of the experiment and following every additional fifth display to determine accuracy (see Hessels et al., 2016, for a description of the calibration process and data preparation). The experiment lasted 10–15 min.

Originally, visual search data were available for 75 infants. Infants were included only when at least 12 fixations were recorded. Fixations were parsed using identification by two-means clustering (Hessels, Niehorster, Kemner, & Hooge, 2017). Only fixations that were not flanked by missing data were included to diminish the chance that fixations were shortened because the eye tracker could not report on data. This led to the exclusion of 17 infants. The median fixation duration (in milliseconds) and the pooled intraindividual standard deviation of fixation duration across testing days were used. Higher scores represented longer fixation duration and more variation in fixation durations, respectively.

Disengagement

The gap–overlap task was used to measure disengagement (Cousijn, Hessels, Van der Stigchel, & Kemner, 2017). After calibration (see Cousijn et al., 2017), 60 trials were presented in random order, evenly distributed over gap, overlap, and baseline conditions. All trials commenced by attracting the infant's attention with the central stimulus—an expanding and contracting (maximum size: $3.3^\circ \times 3.3^\circ$) central clock ($2.1^\circ \times 2.1^\circ$). To maintain the infant's attention, the clock started spinning at 500°/s after fixation. The peripheral stimulus, which was either a sun, cloud, ball, star, or dog ($2.5^\circ \times 2.5^\circ$, positioned 19° left or right from the central stimulus), appeared 600–700 ms after the infant fixated to the central stimulus. The 100-ms jitter was implemented to decrease anticipatory saccades. In the baseline condition, the onset of the peripheral stimulus directly followed the offset of the central stimulus. The peripheral stimulus stayed on-screen until the child fixated it or until 1500 ms elapsed. The peripheral stimulus contracted and expanded or spiraled out of view for 1000 ms after a first fixation. This feedback was combined with various sounds (e.g., a car horn, a bell). During the gap condition, the offset of the central stimulus was 222 ± 35 ms before the onset of the peripheral stimulus. During the overlap condition, the central and peripheral stimuli remained simultaneously and inanimately on-screen.

Data preparation is described in Cousijn et al. (2017). Data were originally available for 68 infants. Infants with fewer than 10 included trials for either the gap or overlap condition were excluded ($n = 19$). Saccadic reaction time was defined as the time between the target stimulus onset and the first fixation on this target. The difference in saccadic reaction time during the gap and overlap conditions across testing days was used, with higher scores representing slower disengagement.

Effortful control

Parent-reported effortful control was determined following the scoring procedure for the Early Childhood Behavior Questionnaire Short Form by averaging the attention focusing, attention shifting, cuddliness, inhibitory control, and low-intensity pleasure subscales (Putnam, Gartstein, & Rothbart, 2006). The 32 questions were answered on a scale from 1 (*never*) to 7 (*always*). Internal consistency was good ($\alpha = .86$). Observed effortful control was assessed with a delay of gratification task (Kochanska et al., 2000). Toddlers were seated, and a bag with a gift inside was presented along with the instruction to wait until the experimenter returned with a bow. Parents were instructed to stay in the room but to remain as neutral as possible. The experimenter left the room and returned after 3 min. Toddlers were filmed, and latencies (in seconds) to touch the bag, open the bag, look in the bag, put a hand in the bag, pull the gift out of the bag, and leave the chair were coded afterward by two coders, with latency scores ranging from 0 (*immediately*) to 180 (*never*). Interrater reliability on 15 videos was good, with Intraclass correlations (ICCs) ranging from .91 to .99. A mean of all latency scores was used and had good internal consistency ($\alpha = .91$). Observed effortful control and parent-reported effortful control were sufficiently correlated ($r = .39$, $p < .001$), and an average score was created. Higher scores represented better effortful control.

Compliance

Parent-reported compliance was measured with the compliance subscale of the Infant Toddler Social Emotional Assessment (Carter & Briggs-Gowan, 2006). All eight questions were answered on a scale from 0 (*not true or seldom true*) to 2 (*completely or often true*). Internal consistency was sufficient ($\alpha = .70$). Observed compliance was coded during a 3-min cleanup, which followed a 12-min play situation with one parent. Parents were cued to instruct their children to clean up toys in a transparent box. Child compliance was coded using an adapted version of the *Dyadic Interaction Coding Manual* (Lunkenheimer, 2009) by two trained coders. Coders coded three forms of noncompliance (dysregulation, passive noncompliance, and refusal), compliance, and other off-task behaviors (e.g., playing, talking). Time spent showing off-task behaviors was not taken into consideration. The percentage of time the child complied, relative to the overall time, was used. Interrater reliability was determined over the percentage compliance in 15 videos and was excellent (ICC = .99). Observed compliance and parent-reported compliance were sufficiently correlated (r = .34, p = .009), and an average score was created. Higher scores represented better compliance.

Results

Preliminary analyses

Table 1 displays descriptive statistics and bivariate correlations. There were medium-sized positive correlations between median fixation duration and variation in fixation duration, between disengagement and fixation duration, and between compliance and self-regulation in toddlerhood. There were no associations between the attention measures in infancy and compliance and self-regulation in toddlerhood. The Hawkins test of normality and homoscedasticity (Jamshidian, Jalal, & Jansen, 2014) indicated that data were missing completely at random (p = .086).

Primary analyses

Two multiple regression analyses were performed to test whether infant fixation duration, variation in fixation duration, and disengagement predicted effortful control and compliance in toddlerhood. These models were estimated in the R package Lavaan (Rosseel, 2012) using maximum likelihood estimation with an asymptotical equivalent of the Yuan–Bentler adjusted chi-square test and robust (Huber–White) standard errors. Missing data were handled with full information maximum likelihood estimation, enabling the analyses to be conducted on the sample of 74 children.

Table 2 shows the results of both multiple regression analyses. For effortful control, chi-square testing against the baseline model indicated that the regression model fitted the data better than a baseline model with uncorrelated variables (χ^2 = 17.42, df = 3, p = .001). Longer fixations and less variation in fixation duration in infancy predicted better effortful control in toddlerhood. However, the individual bivariate correlations between effortful control and both fixation duration and variation in fixation duration were not significant (see Table 1). Thus, the visual attention measures strengthen each other's association with effortful control by accounting for their residuals. Disengagement was unrelated to toddler effortful control. For compliance, chi-square test against the baseline model

Table 1
Correlations and descriptive values.

	M (*SD*) Range	1	2	3	4	5
1. Age in toddlerhood (n = 65)	28.50 (1.20) 26.71–31.80					
2. Fixation duration (n = 58)	314.23 (56.71) 114.99–441.59	−.08				
3. Variation in fixation duration (n = 58)	214.00 (78.93) 73.12–626.52	−.07	.36**			
4. Disengagement (n = 49)	157.01 (71.95) 13.28–321.30	.17	.29**	.13		
5. Effortful control (n = 65)	−0.04 (0.86) −1.77 to 1.71	.05	.22	−.21	−.09	
6. Compliance (n = 65)	0.00 (0.86) −1.55 to 1.77	.02	−.09	−.04	−.04	.30**

Note. The *ns* vary depending on missing data and range between 44 and 65. Values are based on bootstrapped confidence intervals. Parent-reported effortful control (n = 64) ranged from 3.89 to 6.30 (M = 4.98, SD = 0.50). Observed effortful control (n = 58) ranged from 4.33 to 180.00 (M = 108.76, SD = 60.64). Parent-reported compliance (n = 61) ranged from 1.00 to 2.00 (M = 1.52, SD = 0.27). Observed compliance (n = 62) ranged from 0.00 to 100.00 (M = 55.16, SD = 31.52).
* p < .05.
** p < .01.

Table 2
Multiple regression of visual attention in infancy on effortful control and compliance in toddlerhood.

	Effortful control			Compliance		
	B (*SE*)	*β*	*p*	*B* (*SE*)	*β*	*p*
Fixation duration	0.37 (0.09)	.43	<.001	−0.03 (0.11)	−.04	.759
Variation in fixation duration	−0.29 (0.07)	−.34	<.001	−0.28 (0.16)	−.24	.075
Disengagement	−0.10 (0.13)	−.12	.432	0.12 (0.12)	.15	.315

Note. $N = 74$ with full information maximum likelihood. $R^2 = .18$ for effortful control, and $R^2 = .05$ for compliance. For compliance, one extreme influential case on the set of parameters was deleted (generalized Cook's distance [GCD] = 4.31[a]). All predictors were entered into the regression analyses simultaneously. Predictors were standardized to avoid problems related to large differences in variances.

a. GCD values higher than 1.00 may indicate a problem (Cook & Weisberg, 1982). All other GCD values fell within a range of 0.00–0.75 for the compliance model and within a range of 0.00–0.66 for the effortful control model.

indicated that the regression model fitted the data better than a baseline model ($\chi^2 = 8.24$, $df = 3$, $p = .041$). However, none of the visual attention measures predicted compliance. Results were similar when analyses were conducted while controlling for covariates (see online supplementary material).

Discussion

The current study is one of the first to examine whether microtemporal measures of visual attention (fixation duration, variation in fixation duration, and disengagement) predict two aspects of self-regulation (effortful control and compliance) in toddlerhood. The results showed that when all three measures of visual attention are taken into account, longer fixation durations and less variation in fixation duration predicted better effortful control but not compliance. Disengagement did not predict either effortful control or compliance.

Fixation duration and variation in fixation duration predicted effortful control when all variables were entered into the regression analyses simultaneously, indicating that these measures share information that is irrelevant for predicting later self-regulation. This may relate to shared-method variance, given that all measures were obtained through eye-tracking, and to the general observation that reaction time measures and their variances are positively related (e.g., Robinson & Tamir, 2005). The results of this study concord with previous work indicating that longer fixation duration in infancy predicts better parent-reported effortful control in preschool years (Papageorgiou et al., 2014) and that low variation in fixation duration (but not fixation duration) when watching dynamic stimuli is associated with better concurrent cognitive control (Wass & Smith, 2014). In contrast to Wass and Smith (2014), the results of the current study indicate that only the combination of multiple visual attention measures yields sufficiently accurate predictions for effortful control.

Disengagement, a measure that closely relates to the orienting network, was not predictive of toddlers' self-regulation. Interestingly, Nakagawa and Sukigara (2013) demonstrated that, whereas faster disengagement was associated with better concurrent parent-reported self-regulation at 12 months of age, the direction of this concurrent association reversed at 18 and 24 months and became nonsignificant at 36 months. This may relate to a shift in self-regulation, where control is first primarily executed through the orienting network and later is executed through the executive attention network (Posner et al., 2012). It is possible that indicators of the executive attention network are more appropriate predictors of later self-regulation than indicators of the orienting network. In contrast to effortful control, none of the visual attention measures predicted compliance. Because compliance per definition occurs within interactions with others, whereas effortful control also entails relatively independent forms of regulation (e.g., by including focused attention when playing alone and the ability to wait independently), this may indicate that measures of visual attention predict relatively independent forms of self-regulation.

This study has a couple of strengths. First, infant visual attention was measured on 2 testing days, allowing us to obtain robust estimates. Second, we used both objective measures of self-regulation (observations) and measures of self-regulation outside the laboratory context (parent reports). Third, fixation duration and disengagement were measured with commonly used paradigms (gap–overlap and visual search). A limitation of this study is that participants' high socioeconomic status may limit the generalizability of the study. In addition, test–retest reliability for visual search performance (i.e., time to hit target) was too low to examine whether individual differences on this measure predicted self-regulation (Hessels et al., 2016). By including more search trials, future studies could examine whether search performance also predicts self-regulation. Lastly, given the relatively small sample size of the current study, especially when considering the missing data for disengagement, studies with larger sample sizes are needed to confirm these conclusions.

Overall, the current study is one of the first longitudinal multimethod studies showing that microtemporal visual attention measures in infancy can predict effortful control, but not compliance, in toddlerhood. The finding that individual differences in microtemporal measures of visual attention hold information relevant for predicting self-regulation paves the way for new studies aimed at further understanding the nature of these individual differences.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2018.11.012.

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