Individual Differences in Infant Fixation Duration relate to Attention and Behavioral Control in Childhood

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This paper is resubmission/revision of the **PSCI-13-1695-R1:** Individual Differences in Infant Fixation Duration relate to Attention and Behavioral Control in Childhood

This revised manuscript has 4,280 words. The introduction, discussion and acknowledgements sections have 1,907 words (we are using the 2014 regulations regarding the word limit that state that the limit for Introduction, Discussion and Acknowledgements sections is 2,000 words and there is no word limit for Method and Results sections), 3 tables and 1 figure. The Supplementary material includes three figures (FigS1, FigS2, FigS3) and four tables (TableS1, TableS2, TableS3 and Table S4).

Abstract

Individual differences in fixation duration are considered a reliable measure of attentional control in adults. The degree to which individual differences in fixation duration in infancy (0-12 months) relate to temperament and behavior in childhood is largely unknown. One hundred and twenty infants (mean age in months = 7.69, SD = 1.90) participated in an eye-tracking study. Parents completed age appropriate questionnaires about their child's temperament and behavior at follow up (mean age of children = 41.59, SD = 9.83). Mean fixation duration in infancy was positively associated with effortful control (β = .20, R^2 = .02, p = .04) and negatively with surgency (β =-.37, R^2 = .07, p = .003) and hyperactivity-inattention (β =-.35, R^2 = .06, p = .005) in childhood. These findings suggest that individual differences in mean fixation duration in infancy are linked to attentional and behavioral control in childhood.

Keywords: fixation duration, attention, individual differences, temperament, behavior

Introduction

Attention can be defined as a cognitive process that is constituted of a number of highly associated but distinguishable processes (e.g. alerting, orienting, selective, sustained and executive attention) and has both an endogenous component (attention is influenced by internal representations of task goals) and an exogenous component (attention is captured by an event in the environment; Scerif, 2010). It has been proposed that fixation duration could be a stable measure of individual differences in attention across both short and long test-retest intervals (Colombo, Mitchell, Coldren & Freeseman, 1991) and across different tasks (Castelhano & Henderson, 2008; Rayner, Williams, Cave & Well, 2007). Fixation duration refers to the time between saccadic eye movements when the eyes are relatively stable. During a fixation several cognitive processes may occur: foveal visual information is processed and encoded in working memory, the next saccade target is selected from peripheral visual stimuli and the oculomotor program required to bring the target into foveal vision is prepared (Rayner, 1998).

In infancy, fixation duration exhibits a robust developmental change (Colombo, Mitchell, Coldren &Freeseman, 1991). For example, while 1- to 2-month-old infants exhibit a series of long fixations when viewing static stimuli, 3 to 4-month-old infants exhibit a greater proportion of shorter fixations (Johnson, Posner & Rothbart, 1991). This change is thought to reflect a reduction in the early difficulties that infants encounter with disengaging their attention – known as “sticky fixation” or “obligatory attention”. By 4 months, problems with disengaging from static stimuli have largely disappeared (Johnson, et al., 1991).

There is evidence to support the continuity of attention from infancy through toddlerhood to pre-adolescence. The scores of an individual on attentional measures in infancy are correlated moderately with his/her scores on attentional measures in toddlerhood and pre-adolescence, and infants’ attention relates to IQ at 11 years of age (Rose, Feldam, Jankowski & Van Rossem, 2012). Moreover, a recent longitudinal study assessed look duration (average duration of individual looks to targets) in infancy (5, 7 and 12 months of age) and childhood (24 and 36 months of age) and reported that infants' average look duration was positively associated with the behavioral trait of inhibition at 11 years of age (Rose, Feldman, Jankowski, 2012). These findings serve as examples of how individual differences in infant attention may be predictive of executive functions in later childhood.

Executive Attention and Temperament

Based on the fact that a fixation is made up of the conflict between demands for keeping the eyes stationary (in order to encode foveal information) and disengaging attention to shift to peripheral targets (Findlay & Walker, 1999), executive attention – the ability to regulate responses to conflict situations where several responses are possible (Holmboe & Johnson, 2005) is a crucial parameter for one's ability to process and encode efficiently visual information.

Behavioral data indicate that the time that children spend to resolve conflict (in the color-word Stroop task for example) is correlated with scores in parental report measures of effortful control, the temperament trait of one's ability to regulate his/her emotions and to inhibit a dominant response in order to activate a subdominant response (Johnson et al., 1991; Rothbart, Sheese, Rueda & Posner, 2011). Effortful control has been found to correlate negatively with surgency (Rothbart, Ahadi, Evans, 2000). Surgency is the trait aspect of temperament in which a person tends toward high levels of extraversion, motor activity and impulsivity and it has been found to correlate with aggression and externalizing behavior problems in early childhood (Berdan, Keane and Calkins, 2008). Effortful control has also been found to correlate negatively with impulsivity (Eisenberg et al., 2005) and hyperactivity (Gusdorf, Karreman, van Aken, Dekovic &Tuijl, 2011) and to differentiate reliably, typically developing children from children with Attention Deficit Hyperactivity Disorder (ADHD), with the latter scoring significantly lower on measures of effortful control (Samyn, Roeyers, Bijttebier, 2011).

Executive attention and behavioral traits of hyperactivity and inattention

Attention deficit hyperactivity disorder (ADHD) is a condition characterized by symptoms of hyperactivity and inattention; these behaviors are thought to lie on a continuum with normal variation in attention and activity level in the general population (Larsson et al, 2012). Executive attention is impaired in children with ADHD (Dovis, Oord, Wiers & Prins, 2013). A meta-analysis of 83 studies that administered executive functioning measures to a group with ADHD reported that individuals with ADHD showed significant deficits on all executive functioning measures with one of the most prominent and consistent effects to be on measures of response inhibition and planning (Willcutt, Doyle, Nigg, Faraone & Pennington, 2005). Whilst this might be the case there is also evidence to suggest that executive function deficits are, to some extent, dissociable from the diagnostic symptoms observed in individuals with ADHD (Johnson, 2012).

During visual tasks, children with ADHD have difficulties inhibiting responses to salient stimuli and sustaining attention on task-relevant stimuli (Karatekin & Asarnow, 1999). In a video-based eye monitor study, children with ADHD exhibited a trend towards shorter fixations (Karatekin & Asarnow, 1999). Their reduced ability to sustain attention has been demonstrated in a study that required children with ADHD to view two televised stories either in the presence of toys in the room or without toys, and to answer causal relations questions regarding the stories. The direction of the child's gaze was recorded with a video camera. In the toy-presence condition, children with ADHD answered significantly fewer questions in comparison to typically developing children indicating the groups reduced ability to spend time in long looks in order to follow the continuity of the story (Lorsch et al., 2004). Finally an electrooculography (EOG) study has found that, in comparison to typically developing individuals, individuals with ADHD exhibited difficulties suppressing intrusive saccades in a task that required them to maintain steady fixation (Munoz, Armstrong, Hampton &Moore, 2003). If these findings extend to the continuous traits of hyperactivity and inattention in the general population, it would be predicted that hyperactivity and inattention would negatively correlate with mean fixation duration.

The current study

The current study is the first to use eye-tracking combined with a longitudinal design to investigate the degree to which individual differences in infants' attention relates to individual differences in parent report measures of temperament (effortful control and surgency) and behavior (hyperactivity-inattention) in childhood. Eye tracking offers the opportunity to study infants' attention; it is a non-invasive technique that has much higher spatial (~1° of visual angle) and temporal resolution (50 Hz for the Tobii 1750 used in this study) in comparison to video coding. This opens the possibility of analyzing in detail how attention is allocated through individual fixations (Wass et al., 2012).

Based on the evidence from the aforementioned studies, it was hypothesized that mean fixation duration in infancy would be: 1) positively associated with effortful control in childhood; 2) negatively associated with surgency in childhood and 3) negatively associated with hyperactivity-inattention in childhood.

Method

Sample and procedure

The participant pool comprised of 271 children (141 males, 130 females), born between March 2008 and December 2010, who took part in an eye-tracking study when they were between 4-to 10-months of age (mean age in months = 7.69, range = 6.34). Their parents were invited to participate in the present follow up study by e-mail, telephone, and post between February 2012 and May 2012. One hundred and seventy two participants accepted the invitation (response rate = 63.5%). Following the acceptance of the invitation, they were posted an information sheet, two copies of a consent form and a questionnaire booklet. Parents posted back the questionnaire booklet and a signed copy of the consent form using a prepaid envelope. Fifty-one participants did not return questionnaires. One participant was excluded from the analysis because of insufficient eye tracking data. One hundred and twenty participants (55 males, 65 females; mean age of the children in months when the parents competed the questionnaire = 41.59, SD = 9.83) took part in this follow up study. The majority of infants were Caucasian, of middle socioeconomic status, and residents of London.

The project was granted ethical approval by the Department of Psychological Sciences, Birkbeck University of London’s departmental ethics committee.

Eye Tracking study apparatus and stimuli

The infants’ looks were monitored with a Tobii 1750 eye-tracker. All stimuli were presented on a 17-inch monitor attached to the eye-tracker. Infants were calibrated with the standard 5-point Tobii infant calibration procedure in the four corners and center of the screen. Dynamic video presentations of faces, red flashing squares, multimodal objects, and moving shapes were presented to all infants in the study. The eye tracking study explored how infants learn from different attention cues or no attention cues about multimodal objects (Wu & Kirkham, 2010) and statistically coherent shapes (Wu, Gopnik, Richardson & Kirkham, 2011).

The current analyses disregarded the slight stimulus differences and the location of fixations (in line with Wass et al., 2012). While the stimuli across all conditions were very similar, the potential effect of each participant's condition on the reported association was treated as covariate in the regression analysis to address any differences based on stimulus presentation. The apparatus, stimuli, design and procedure of the eye tracking study are described in detail in the following manuscripts: Wu & Kirkham, 2010; Wu, et al., 2011.

Measures

Eye tracking derived measure. Fixation duration was extracted from the infants' raw eye tracking data that included information on periods during which the infants' eyes were stable, periods during which the velocity of the gaze was high and periods when gaze was lost due to blinks. Fixation detection was performed using a two-stage approach. First, Matlab scripts designed by Wass et al., (2012) specifically to cope with low quality infant data were used to detect fixations. Briefly, the scripts use a bilateral filtering algorithm written by Ed Vul (Frank, Vul, & Johnson, 2009; based on Durand & Dorsey, 2002) to smooth the data; they interpolate the data in order to fill periods of data loss up to 150ms; they perform velocity thresholding by using a velocity threshold of 35˚/sec; they only keep as "real" fixations, those that meet the following criteria: a) fixation is a complete fixation. Complete fixations are those that are begun and ended by a saccade, rather than a smooth pursuit, or blink; incomplete fixations were excluded from any further analysis); b) displacement since previous fixation is >0.25˚; c) average velocity during previous fixation is < 12˚/sec; d) velocity in the three samples immediately preceding the saccade is < 12˚/sec; e) binocular disparity is not above 3.6˚; f) the fixation identified has a minimum temporal duration of 100ms (Wass et al., 2012). Only 33% of the fixations detected by the standard-dispersal algorithms passed the stringent quality control of Wass et al., (2012) algorithms (mean N of fixations = 147; SD = 103).

Subsequently, in order to further improve the quality of the data and to correct for the limitation of the algorithms, which is that they are not able to distinguish efficiently between fixations and sections of smooth pursuit (Wass et al., 2012), a “supervised” approach was applied to the data derived by the algorithms, which consisted of hand moderating the data returned by the algorithms and correcting for sections of smooth pursuit, which have been identified as fixations. To do that, an in-house fixation detection tool, GraFIX was used (Saez de Urabain, Johnson and Smith, in press). GraFIX allows variable quality of gaze data to be accounted for across several stages of both automated and hand moderated processing. In the current analysis GraFIX was used only to hand-moderate the data derived by Wass et al., (2012) algorithms via inclusion, exclusion or modification of artificial fixations. This procedure has been shown to be the most efficient and accurate method for identifying fixations in noisy gaze data like that encountered in infants (Saez de Urabain, Johnson, & Smith, in press).

On average, sixty-four additional fixations per participant were identified in the hand moderation analysis (mean N of fixations = 211; SD N of fixations = 125). The amount of fixations detected per participant was used as covariate in the regression analysis. The hand-coded data were significantly correlated ($r = .57$, $p < .000$) with the data derived by the algorithms (Wass et al., 2012) and were the data used in the analysis. The reliability of the algorithms used in the analysis has been shown on multiple infants’ datasets (see Wass et al., 2012 for details). The significant correlation between the hand-moderated data and the data derived by the algorithms suggests that, while potential errors of the automatic algorithms were corrected (hence why the correlation between the hand moderated data and the data derived by the algorithms was not at unity), the data derived by the hand moderation analysis using GraFIX were not deviating majorly from the original pre-hand-moderated data.

Questionnaires. Eight subscales of the short form of the *Early Childhood Behaviour Questionnaire* parent report (ECBQ; Putnam, Jakobs, Gartstein & Rothbart, 2010) that load onto two factors, namely effortful control and surgency, were employed to assess temperament in preschool age children (19-36 months of age). The scores on the ECBQ scale of effortful control represented the average score of the ECBQ subscales of attentional focusing (6 items), inhibitory control (6 items), low-intensity pleasure (6 items) and perceptual sensitivity (5 items). The scores on the ECBQ scale of surgency represented the average score of the ECBQ subscales of activity level (8 items), high-intensity pleasure (6 items), impulsivity (4 items) and shyness (5 items reversed)). The rater reported the frequency of a particular behavior (example question for effortful control: "*Your child can wait before entering into new activities if s/he is asked to;* example question for surgency: "*Your child likes to play so wild and recklessly that he/she might get hurt.*"), on a seven-point scale (ranging from "never" to "always") and the subscales scores represented the mean score of all items applicable to the child. The mean instead of the sum score of the items was used to ensure that missing data would not affect the scales' final score. The ECBQ scales of effortful control and surgency showed excellent internal consistency (Cronbach's alphas = .86 and .85, respectively).

The equivalent eight subscales of the short form of the *Childhood Behaviour Questionnaire* parent report (CBQ; Putnam and Rothbart, 2006) were employed to assess effortful control and surgency in school age children (36-58 months of age). The scores on the CBQ scales of effortful control and surgency represented the average score of the same subscales as for the ECBQ. The CBQ scales of effortful control and surgency showed excellent internal consistency (Cronbach's alphas = .81 and .89, respectively).

To assess hyperactivity-inattention in preschool children the *Revised Rutter Parent Scale for Preschool Children* parent report (RRPSPC; Hogg et al., 1997) was used. The RRPSPC hyperactivity-inattention scale consisted of 4 items and the rater reported on the frequency of a particular behavior (e.g. "*Restless; runs about or jumps up and down, doesn't keep still*") on a three-point scale ("*not true"; "sometimes true"; "certainly true*").

To assess hyperactivity-inattention in school age children the SDQ hyperactivity-inattention scale parent report version of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) was employed. The SDQ hyperactivity-inattention scale consisted on 5 items that is of identical format to the RRPSPC and it is a reliable and valid measure of hyperactivity-inattention of children age 3 to 16 year olds (Goodman, 1997). The SDQ and RRPSPC scales of hyperactivity-inattention showed good and moderate internal consistency respectively (Cronbach's alphas = .76 and .54, respectively).

Statistical Analyses

Descriptive Statistics. Mean fixation duration and the questionnaire data were explored using descriptive statistics in SPSS version 18.0. Due to skewness of the data, Van der Waerden's transformation (Lehmann, 1975) was used to normalize the data before further statistical analyses were undertaken. Levene's test was used to test the assumption of equality of variances between males and females and Analysis of Variance (ANOVA) was performed to test for significant mean sex differences (at $p < .01$). No statistically significant sex differences were observed. Table S1 in the Supplemental material available online presents the mean sex differences analyses.

Correlations. Partial correlations were performed to test for significant correlations (at $p < .05$) between the questionnaire scales of effortful control, surgency and hyperactivity-inattention. Sex and age of the child when the parents completed the questionnaires were used as covariates. In addition, whether the preschool or school age versions of the questionnaires were used was included as a covariate in the analysis.

Regressions. Multiple linear regression was performed to test for significant associations (at $p < .05$) between mean fixation duration in infancy with effortful control, surgency and hyperactivity-inattention in childhood. The effects of age when the child took part in the eye tracking study and the age of the child when the parents completed the questionnaire, the type of the questionnaire booklet, sex, total number of trials (completed by participants in the eye-tracking studies), total number of fixations detected and the particular condition that each infant took part in the eye-tracking study were treated as covariates in the regression analysis in order to investigate to what degree variation in fixation duration in infancy accounted for variation in scores on effortful control, surgency and hyperactivity-inattention in childhood. Finally, the multiplicative effect of infant fixation duration and age of the infant (interaction effect between fixation duration and age of the infant) on explaining variation in effortful control, surgency and hyperactivity-inattention was explored using a moderated multiple regression model (Baron and Kenny, 1986).

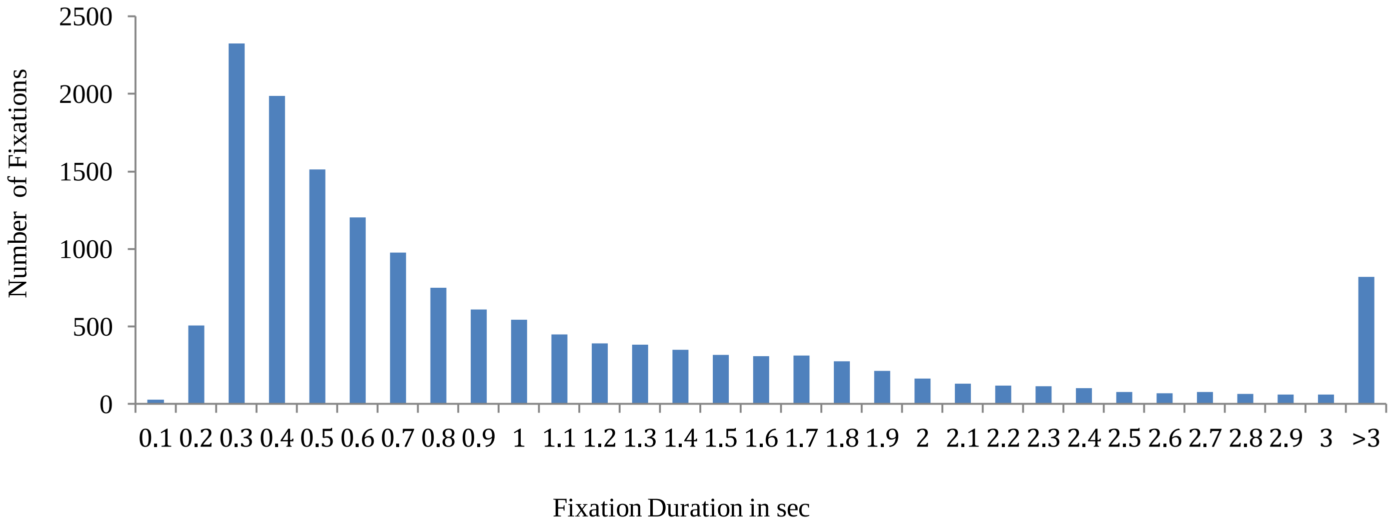
Results

Descriptive Statistics. Descriptive statistics for mean fixation duration and for the scales of effortful control, surgency and hyperactivity-inattention are shown in Table 1. Figure 1 presents the distribution of fixations for all participants. Table S2 in the Supplemental material available online presents the descriptive statistics for the ECBQ and CBQ scales of effortful control and surgency and the RRPSPC and SDQ scales of hyperactivity-inattention.

Table 1. Descriptive Statistics for Mean Fixation Duration, Effortful Control, Surgency and Hyperactivity-inattention for all participants

	N = 120 (19-58 months of age)			
	Mean Fixation Duration	Effortful Control	Surgency	Hyperactivity-Inattention
N	120	120	120	120
Mean	.70	5.34	4.59	2.76
SD	.12	.64	.78	2.01
Variance	.01	.41	.61	4.04
Median	.69	5.35	4.55	2.00
Mode	.48	5.42	4.52	2.00
Range	.68	2.69	4.08	10.00
Kurtosis	2.54	-.50	.36	1.56
Skewness	1.19	-.03	-.05	1.08

Fig 1. Distribution of Fixation Duration for Total Number of Participants



Infant Age and Fixation Duration. To explore the effect of age on infant fixation duration, a regression analysis was performed with infants' age (continuous variable measured in months) as an independent variable and infants' mean fixation duration as dependent variable. The condition that each participant took part in the eye tracking study, sex, number of fixation detected and number of trials that participants took part in the eye tracking study were treated as covariates. Age of the infant did not significantly associate (at $p < .05$) with mean fixation duration ($\beta = .23$, $R^2 = .01$, $p = .07$).

Correlations between Effortful Control, Surgency and Hyperactivity-Inattention in Childhood. Correlations between effortful control, surgency and hyperactivity-inattention are shown in Table 2 for all groups. Effortful control was correlated significantly (at $p < .05$) with surgency ($r = -.17$, $p = .05$) and hyperactivity-inattention ($r = -.52$, $p = .000$). Surgency was correlated significantly with hyperactivity-inattention ($r = .26$, $p = .000$).

Table 2. Correlations between Effortful Control, Surgency and Hyperactivity-Inattention in Childhood

	N = 120 (19-58 months of age)		
	Effortful Control	Surgency	Hyperactivity-Inattention
Effortful Control	1.00	-.17*	-.52**
Surgency	-.17*	1.00	.26**
Hyperactivity-Inattention	-.52**	.26**	1.00

*** p < 0.01, * p < 0.05*

Multiple Linear Regression between Fixation Duration in Infancy and Effortful Control, Surgency and Hyperactivity-Inattention in Childhood. The results of the multiple linear regression for mean fixation duration in infancy (independent variable) with effortful control, surgency and hyperactivity-inattention in later childhood (dependent variables) are shown in Table 3. Mean fixation duration was associated significantly (at $p < .05$) with effortful control ($\beta = .20$, $R^2 = .02$, $p = .04$), surgency ($\beta = -.37$, $R^2 = .07$, $p = .003$) and hyperactivity-inattention ($\beta = -.35$, $R^2 = .06$, $p = .005$). Scatter plots for the reported associations are shown in Figures S1, S2 and S3 in the Supplemental material available online for effortful control, surgency and hyperactivity-inattention, respectively. Table S3 in the Supplemental material available online presents the results of the multiple linear regression for the overall model. The overall model represents the additive effect of the independent variable (mean fixation duration) and the effect of all the covariates (age when the child took part in the eye tracking study; the age of the child when the parents completed the questionnaire; the type of the questionnaire booklet; sex; total number of trials completed by participants in the eye-tracking studies; total number of fixations detected; and the particular condition that each infant took part in the eye-tracking study) on accounting for variation in the dependent variables (Effortful Control, Surgency and Hyperactivity-Inattention).

Table 3. Linear Regressions between Fixation Duration in Infancy and Effortful Control, Surgency and Hyperactivity-Inattention

N=120							
Independent Variable: Mean Fixation Duration							
Dependent Variable	B	β	t	95% CI for β Lower Bound	95% CI for β Upper Bound	R^2	p-value
Effortful Control	.14	.20	2.00	.001	.28	.02	.04
Surgency	-.30	-.37	-3.05	-.51	-.10	.07	.003
Hyperactivity-Inattention	-.76	-.35	-2.90	-1.28	-.24	.06	.005

Note: The "B" and "β" refer to the unstandardized and standardized regression coefficients respectively followed by the "t-statistic". The "R^2" represents the variance explained by the independent variable on the dependent variables after regressing out the effect of the covariates; finally, the p-value represents the value of statistical significance of the effect of the independent variable on the dependent variables, while keeping constant the effect of the covariates.

To shed light on the developmental mechanisms that link attention in infancy to temperament and behavior in childhood the interactive effect of infant fixation duration and age of the infant (fixation duration x infant age) on explaining variation in effortful control, surgency and hyperactivity-inattention was explored. Table S4 in the Supplemental material available online presents the results of the regression model. A significant interaction effect between mean fixation duration and infant's age on children surgency was observed. Fixation duration x infant age interaction was significantly associated with surgency in childhood (β = -.20, R^2 = .03, p = .05). The result suggests that the direction of the association between mean fixation duration and surgency remains the same (negative), irrespective of the age of the infant; the fact that the association is significant suggests that the variance of childhood surgency accounted for by variation in infant fixation duration increases as the age of the infant increases.

Discussion

The aim of this study was to investigate the degree to which individual differences in fixation duration in infancy (a measure of attentional control) relate to the temperament domains of effortful control and surgency and the behavioral trait of hyperactivity-inattention in childhood.

As hypothesized, longer mean fixation duration was indicative of higher levels of effortful control and lower levels of surgency and hyperactivity-inattention. These findings show for the first time a longitudinal association between infant fixation duration (derived from eye-tracking data) and child effortful control, surgency, and hyperactivity-inattention. The reported associations were of moderate magnitude, with the proportion of variance to be explained by mean fixation duration in infancy being 2%, 7% and 6% for effortful control, surgency and hyperactivity-inattention in childhood, respectively. Moderate effects are to be expected given that many factors within a dynamic developmental framework operate to produce individual variability on high-level behaviors (e.g. hyperactivity-inattention; Nigg, 2009).

These findings should be considered in light of some limitations. The Cronbach's alpha reported for the RRPSPC hyperactivity scale was moderate. It will be important to test if the findings replicate in other samples. There was attrition in the sample due to the longitudinal nature of the study. Nevertheless, the final sample was powered to detect moderate effects and was considerably larger than the sample size of most studies in infant eye tracking research (typically 10-20). Furthermore, there was unavoidable attrition in usable eye tracking data within participants. This was due to fact that infant eye tracking data are generally of poorer quality (less precise and with more lost samples) compared to adult data (Wass et al., 2012). Because of this, considerable attention was given to ensure that the observed variation per participant reflected individual variation in fixation duration and not noise produced by extraneous components (e.g. data quality). Fixation parsing algorithms, designed specifically to detect fixations in low quality infants' data and hand moderation was performed to improve the quality of the data used in the regression analysis. This two-stage approach has significant advantages over using fixation detection algorithms or hand coding alone. More specifically, it provides stability in the criteria used to detect fixations and with the flexibility to address limitations of the automatic fixation parsing algorithms. Finally, a limitation of the study was the reliance on parent report of children's behavior and temperament. While parents are typically most familiar with their children's behavior, all types of raters include some bias. Future research should consider collecting data from multiple raters or employing additional objective measurements of behavior.

Previous research indicates that there is continuity of attention from infancy through toddlerhood to pre-adolescence and that infants' looking time relate to IQ and the behavioral trait of inhibition at 11 year of age (see Rose et al., 2012). The findings of our study demonstrate that mean fixation duration in infancy is linked to attentional and behavioral control in early childhood. The data also support the notion that fixation duration could constitute a measure of individual differences in the efficiency of young infants' ability to regulate and control their attention. This is of great importance considering that, while the temperament trait of surgency emerges in the first year of life, effortful control develops in the second and third year of life and beyond, making it difficult to find appropriate measures to assess aspects of executive attention in infancy (Rothbart, Sheese & Posner, 2007). As such, studying fixation duration in infancy could have significant implications for understanding the mechanisms through which executive control develops.

Investigating the causes of individual differences in voluntarily control of attention as early as in infancy might inform early intervention practices that will aim to improve aspects of executive attention. Executive attention is an important network for the acquisition of a wide variety of skills that draw upon general intelligence (Rothbart et al., 2007). Finally, given the role of effortful control in differentiating typically developing children from children with ADHD (Samyn et al., 2011) and the association between fixation duration in infancy with later effortful control and hyperactivity-inattention, reported here, a tentative idea for future research would be to explore whether fixation duration in infancy could be used to indicate individuals at risk for developing ADHD.

Authors' Contribution

Angelica Ronald developed the study concept and held the grants that supported this research. All authors contributed to the study design. Kostas A Papageorgiou formulated the hypotheses and performed the questionnaire data collection, the data analysis and write up of this manuscript under the supervision of Angelica Ronald and Tim J Smith. Rachel Wu and Natasha Z Kirkham collected the eye tracking data. Mark H Johnson provided with critical revisions during the write up of this manuscript.

The authors have read and approved the final version of the manuscript and declare that they have no conflicts of interest.

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