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Chaotic home environment is associated with reduced infant processing speed under high task demands

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ABSTRACT

Early adversity has profound long-term consequences for child development across domains. The effects of early adversity on structural and functional brain development were shown for infants under 12 months of life. However, the causal mechanisms of these effects remain relatively unexplored. Using a visual habituation task we investigated whether chaotic home environment may affect processing speed in 5.5 month-old infants ($n = 71$). We found detrimental effects of chaos on processing speed for complex but not for simple visual stimuli. No effects of socio-economic status on infant processing speed were found although the sample was predominantly middle class.

Our results indicate that chaotic early environment may adversely affect processing speed in early infancy, but only when greater cognitive resources need to be deployed. The study highlights an attractive avenue for research on the mechanisms linking home environment with the development of attention control.

1. Introduction

During the early years of life home environment is the primary space where children learn and develop. Bronfenbrenner's bioecological model highlights the role of both the social and the physical microsystem for early development (Brofenbrenner & Morris, 2006). While the majority of research was historically focused on the social microsystem, early work by Wachs, Evans and others demonstrated the influence of physical home environment on the development of young children (Evans & Maxwell, 1997; Wachs, 1979, 1989, 1993). What emerged from this work was the idea that the lack of temporal regularity, high levels of crowding and noise have detrimental effects on cognitive (Swanson, Valiente, & Lemery-Chalfant, 2012; Vernon-Feagans et al., 2012) and socio-emotional functioning (Fiese et al., 2002).

The insufficient structuring of the home environment is captured well by the construct of “chaos”: the presence of crowding, confusion and noise as well as the lack of routines and high unpredictability (Matheny, Wachs, Ludwig, & Phillips, 1995). Household chaos is associated with psychological distress among middle school children (Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005) and has long-term detrimental effects on child cognitive development (Berry et al., 2016; Petrill, Pike, Price, & Plomin, 2004; Vernon-Feagans et al., 2012), academic achievement (Hanscombe, Haworth, Davis, Jaffee, & Plomin, 2011; Swanson et al., 2012) and mental health (Deater-Deckard et al., 2009; Wang, Deater-Deckard, Petrill, & Thompson, 2012).

Since the majority of studies measuring physical home environment were conducted on families experiencing poverty, chaos has

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often been related to poverty (see: Evans, Eckenrode, & Marcynyszyn, 2009). However, existing evidence suggests that household chaos is a separate construct from poverty (as measured by socio-economic status, SES) and it either predicts child outcomes independently of SES or mediates those effects (Brace et al., 2001; Chen, Cohen, & Miller, 2010; Deater-Deckard et al., 2009; Hart, Petrill, Deater Deckard, & Thompson, 2007; Shelleby et al., 2014; Vernon-Feagans et al., 2012; Wang et al., 2012). Chaos is also found in households of families not experiencing poverty (see Valiente, Lemery-Chalfant, & Reiser, 2007), strongly suggesting that some specific characteristics of physical home environment may affect child development in middle-class families just as well. Considering the constructs of chaos and poverty, Vernon-Feagans, Willoughby, and Garrett-Peters (2016) suggested that chaos is one of the potential proximal mechanisms that may explain the effects of poverty on parental behaviour and child outcomes (Bronfenbrenner & Evans, 2000; Vernon-Feagans et al., 2012).

Chaos affects infant development through influence on parental behaviour. In noisy, crowded environments caregivers are less responsive, less stimulating and less likely to vocalize or provide scaffolding (Wachs, 1989, 1993). They are also more interfering with child's activity, while elevated noise levels reduce parental sense of efficacy (Corapci & Wachs, 2002). For older children high chaos is associated with less frequent positive responses of the parents to child's emotional reactions (Valiente et al., 2007).

The physical properties of chaotic home environment influence children's capacity to process relevant information in addition to the effects on caregiving. Wachs, Morrow, and Slabach (1990) found associations between lower crowding and availability of shelter from noise with lower variability in visual recognition memory in 3-month-olds. In pre-schoolers high levels of noise in the household increase reaction times in a visual search task (Heft, 1979), while in older children noise impairs auditory discrimination and leads to reading difficulties (Cohen, Glass, & Singer, 1973). Long-term effects of environmental noise were found for speech processing and reading, and long-term memory of school-aged children (Evans & Maxwell, 1997; Evans, Hygge, & Bullinger, 1995). Similarly, research using directly the construct of chaos found associations of high chaos with less attention focusing, reduced responding to social cues and externalizing problems (Dumas et al., 2005). Together, these results suggest that household chaos likely affects information-processing capacities from young age. Existing research on infant auditory processing suggests that some of these effects may begin to emerge before the first birthday. Five-month-olds show some ability to selectively attend to a voice in the presence of competing voices (Newman, 2005), but noise affects their speech processing (Polka, Rvachew, & Molnar, 2008). Thus it is likely that persistent crowdedness- and noise-related chaos in the household may affect information processing already in infancy.

How may adverse environment affect information processing in infancy? Recent research from adults experiencing poverty offers some insights. It shows that poverty itself impedes cognitive capacity and may lead to decreased cognitive performance (Mani, Mullainathan, Shafir, & Zhao, 2013). This can be explained either by poverty acting as a distractor (Mani et al., 2013), or poverty leading to self-regulatory failure (Dang, Xiao, & Dewitte, 2015; Hofmann, Vohs, & Baumeister, 2012). These results are in contrast to a large literature that attributes the long-term effects of early adversity to mechanisms critically dependent on specific external factors, such as prenatal exposure to toxins or elevated cortisol. The role of internal, cognitive mechanisms in mediating the effects of adverse early environment during the first years of life is less well understood. Recent research focused on the mediating role of stress-related physiological systems (Blair & Raver, 2015). It has demonstrated that early adversity affects the development of executive functions by reducing the flexibility of stress responses Blair, Raver, Granger, Mills-Koonce, & Hibel, 2011; Evans, 2003), highlighting the role of infant's reactivity and regulation of arousal (Ursache, Blair, Stifter, & Voegtline, 2013).

To date, the majority of research on early adversity has focused on socio-economic deprivation, suggesting causal pathways between socio-emotional environment and children's cognition. While classic studies suggest that physical properties of early environment are closely related to information processing already in infancy (Wachs et al., 1990), such causal links that may exist independently from SES have not been fully investigated. To address this gap in the literature we investigated whether chaotic home environment may affect infants' use of cognitive resources. We studied a sample of infants coming from predominantly middle class families without extreme levels of chaos to investigate whether typical variation in home environment contributes to early emerging individual differences in information processing.

Given the decreased use of cognitive capacities in adults facing adversity (Mani et al., 2013) we hypothesized that a similar, but simpler mechanism may exists early in life. The daily experience of unpredictable and uncontrollable environment may affect infant's cognitive capacities, especially in more demanding situations. Under low task demands information processing may be unimpaired, but reduced availability of cognitive resources due to greater chaos would lead to decreased performance under higher task demands. We tested this prediction in a habituation task by presenting 5.5-month-olds with simple and complex visual stimuli. Infants at that age have sufficient control over their eye movements (Braddick & Atkinson, 2011; Johnson & Tucker, 1996) and relatively well established patterns of attention during interactions (Messinger, Ekas, Ruvolo, & Fogel, 2012), to reveal potential effects of environment on their visual stimulus processing. Task difficulty was conceptualized as the amount of stimulus information, i.e. stimulus complexity, which affects infant looking durations, as well as novelty/familiarity preferences (Hunter & Ames, 1988; Karmel & Maisel, 1975). Moreover, individual differences in looking durations have been linked to differences in cognitive performance already at 4 months of age (Colombo, Mitchell, Coldren, & Freeseman, 1991; Frick & Colombo, 1996; Stoecker, Colombo, Frick, & Allen, 1998). This suggests that looking duration during visual habituation can be used as a measure of infant processing speed (see Colombo & Cheatham, 2006; Colombo & Mitchell, 2009). Thus, in the current study we measured infant's peak looks to simple and complex stimuli in an infant-controlled habituation to assess their processing speed under lower (simple stimuli) and higher (complex scenes) task demands. We expected to see increased processing times for the complex but not for the simple stimuli in infants from families with higher household chaos.

Table 1
Demographic data for the study sample.

Measure	*M*	SD	Min.	Max.
Mother's age at childbirth [years]	30.7	3.9	23.0	39.0
Mother: completed years of education	17.3	2.1	11	24
Father: completed years of education	16.3	2.6	11	22
Household income per capita (monthly, PLN)	2052	655	581	4000
Mother unemployed (*N* = 71)	8		11.3%	
Father unemployed (*N* = 70)	1		1.4%	
Number of family members				
2	2		2.8%	
3	51		71.8%	
4	14		19.7%	
5+	4		4.6%	
Number of children				
1	57		80.3%	
2	11		15.5%	
3	3		4.2%	

2. Methods

2.1. Participants

Eighty-three healthy infants took part in the study. Twelve participants did not complete the eye-tracking task due to fussiness ($N = 10$) or experimenter's error ($N = 2$). The final sample consisted of 71 infants ($M = 169.65$ days, SD = 10.33, range 150–189 days; 35 girls and 36 boys). All participants were Caucasian, reflecting the ethnic composition of the local population. Infants were born between 36 and 42 weeks of pregnancy ($M = 39.31$; SD = 1.42) with birth weight ranging between 2380 and 4600 g ($M = 3448.31$; SD = 455.50). None of the children had birth complications or any major medical conditions. No parent reported family risk of autism. The twelve excluded infants did not differ from the rest of the sample in terms of their sensory threshold ($U = 318.50$, $p = .99$) or CHAOS scores ($U = 351.50$, $p = .96$).

Demographic data (see Table 1) was collected in an interview with one or both parents conducted by the experimenter towards the end of the session. Participants were predominantly middle-class families with higher education and lived in a city with > 1.5 million inhabitants. Maternal age at childbirth ranged between 23 and 39 years ($M = 30.72$; SD = 3.91). In terms of income levels, seven families (17% of the sample) lived on or below the official governmental poverty line (data from Institute of Labour and Social Studies, 2015). This rate is comparable with national poverty rates. For subsequent statistical analyses household income was transformed into a categorical variable with families living below or above median income falling into separate categories. All fathers except one were in employment (data was available for 70 fathers), while for mothers 63 (88.7% of the sample) were in employment with the remaining 8 mothers (11.3%) being unemployed for more than 6 months. There were two single-parent households. Only one participant was in regular daycare, looked after by someone else than the mother on a daily basis. For all remaining 70 participants the mother was reported to spend most of the time with the child during the month preceding the visit to the lab.

The study was approved by the local institution's ethics committee. All parents gave written informed consent prior to the testing and received a small gift (baby book) and a certificate of their participation.

2.2. Standardized measures

2.2.1. CHAOS

Maternal perception of the level of environmental confusion and organization of the household was measured with the Chaos, Hubbub and Order Scale (Matheny et al., 1995), which was culturally adapted and translated into local language (Dragan, Marczuk, Niedźwiecka & Tomalski, unpublished materials) obtaining a satisfactory reliability level for the study sample (Cronbach's alpha = .71). This 15-item scale with a true/false response format has been used in a number of studies, showing good validity and stability while being to a large extent independent of family SES (Dumas et al., 2005; Matheny et al., 1995). Higher scores on the scale indicate a more chaotic and disorganized home environment.

2.2.2. Infant-Toddler Sensory Profile

ITSP measures sensory processing along two dimensions: sensory thresholds (high/low) and regulation (passive/active) producing scores in four subscales: Low Registration (awareness of sensory stimulation with higher scores reflecting greater hypo-sensitivity), Sensation Seeking (tendency to actively seek stimulation), Sensory Sensitivity (ability to notice sensory stimulation with higher scores indicating greater hyper-sensitivity) and Sensation Avoiding (tendency to actively avoid sensory stimulation) (Dunn, 2002). The scores for the two latter subscales added together provide a Low Threshold score, which is an estimate of infant's sensory thresholds. Previous work indicated that ITSP Low Threshold subscale as a construct is closely related to temperamental dimension of reactivity (DeSantis, Harkins, Tronick, Kaplan, & Beeghly, 2011). Given that past research has found associations between physical home environment and dimensions of temperament (Wachs et al., 1990), we controlled for infant sensory thresholds in our main regression analysis that tested whether CHAOS scores predict infant looking. Low Threshold scores were entered as a predictor in these regressions (see Section 3). Higher scores on the Low Threshold subscale indicated lower sensory thresholds. We used an existing local language adaptation (Tomalski, Pisula, Kawa, Niedźwiecka, unpublished materials), with reliability scores somewhat lower than the original for all subscales (Cronbach's α range .54–.64), bar Sensation Avoiding (α = .35). This may reflect lower reliability of the Sensation Avoiding subscale (original α = .56) compared with the other subscales (α range .61–.78; Dunn, 2002). Importantly, the reliability of the Low Threshold subscale in the current sample (α = .62) was deemed acceptable for use in subsequent statistical analyses.

2.2.3. Maternal anxiety

Low SES is associated with increased levels of parental stress and anxiety about the child (Clearfield, Carter-Rodriguez, Merali, & Shober, 2014; Perkins, Finegood, & Swain, 2013). Since the level of maternal state anxiety may affect infant eye-tracking performance, just before the session it was measured using the State-Trait Anxiety Inventory, STAI (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), available with norms in the local language adaptation (Spielberger, Strelau, Tysarczyk, & Wrzesniewski, 1987). Scores from the State Anxiety subscale were used to control for maternal anxiety levels during the testing session.

All three questionnaires were always completed by the mother.

2.3. Eye-tracking task and procedure

2.3.1. Habituation task

An infant-controlled habituation task (Courage, Reynolds, & Richards, 2006) measured infant look durations in response to repeated stimuli. A version developed by Wass and colleagues was used (Wass, Porayska-Pomsta, & Johnson, 2011; Wass, 2014). Altogether four different still images were presented in a randomized order: two simple geometric shapes (a diamond and a cross on a uniform background) and two attractive complex scenes (flowers and fish). Differing stimulus complexity of these stimuli was previously confirmed (Wass & Smith, 2014) by a feature congestion analysis, which measured the level of visual clutter (i.e. how difficult it would be to add a new item to the scene in order to draw attention, see Rosenholtz, Li, & Nakano, 2007).

2.3.2. Procedure

Infants were seated on the mother's lap, approximately 60 cm from the stimulus monitor. Eye-tracking data was collected using a Tobii T60XL eye-tracker (Tobii Inc.) with a 24″ monitor, 60 Hz sampling rate and 0.5° accuracy (value provided by the manufacturer). A five-point infant-friendly calibration was performed, with each infant successfully calibrating at least 4 points. The calibration involved sequential presentation of a looming colourful stimulus in the centre of the screen and at each corner until the infant fixated it (or until timeout at 2 s). The stimuli were presented using Matlab Psychophysics Tollbox (Brainard, 1997; Kleiner et al., 2007) and Talk2Tobii package (Deligianni, Senju, Gergely, & Csibra, 2011). The habituation task was part of a battery of eye-tracking tasks (not described in the current report) and was presented in two parts during the session in two pseudorandom orders, counterbalanced between subjects. The entire task lasted < 6 min.

Each trial commenced once the participant had fixated a central attention-getter and ended when he or she had looked away from the screen for > 1 s. To confirm the continuous recording of eye-gaze position a re-fixation target was briefly presented every 15 s. Subsequent analysis confirmed that this did not affect the timing of look duration (Wass & Smith, 2014). Following the end of a trial, a fixation target and a brief auditory stimulus (< 1 s) were presented. If the subject fixated the target, the next trial started immediately; if not, a sequence of different fixation targets and auditory attention getters was repeated. Thus, the habituation procedure did not go forward (i.e. the habituation stimulus was not presented on the screen) unless the infant successfully fixated the fixation target. Habituation stimuli were re-presented until two successive looks were less than 50% of the longest unbroken look so far, or the total presentation length exceeded 120 s. The visual stimuli were presented in a random order.

2.3.3. Habituation measures

Peak look duration was calculated separately for each image and then averaged. Average peak look for simple and complex stimuli was used as a measure of infant processing speed (see Colombo & Cheatham, 2006). Thus, shorter look durations indicated more efficient processing, while longer durations–less efficient processing. Peak look durations were log10-transformed for the purpose of conducting parametric analyses (note that non-transformed values are given in Table 2).

Table 2
Descriptive data for questionnaire measures of maternal anxiety (state), household chaos, sensory threshold and for peak look duration (s) in the habituation task.

Variable	*M*	SD	Min.	Max.
STAI – Maternal state anxiety	31.15	7.27	20	55
Chaos	2.04	2.14	0	9
ITSP – Low threshold	68.79	6.66	53	81
Habituation task – Peak look (s)				
Simple stimuli (s)	9.83	6.60	1.03	42.29
Complex stimuli (s)	16.18	14.26	1.02	87.25

Table 3
Pearson correlation coefficients for control, predictor and dependent variables.

	1.	2.	3.	4.	5.	6.	7.
1. Age	–						
2. Gestational age	.02	–					
3. Birthweight	−.06	.45**	–				
4. Maternal age	−.02	−.03	.01	–			
5. STAI – Maternal state anxiety	.02	.04	−.01	−.10	–		
6. ITSP – Low threshold	−.11	−.22	.01	−.28*	−.29*	–	
7. Chaos	−.05	.03	.11	.05	.16	.05	–
8. Peak look simple stimuli	−.01	.12	−.08	.14	−.11	.13	.10
9. Peak look complex stimuli	.08	.02	.05	.24*	−.16	.28*	.24*

Significant results are indicated with an asterisk:
* $p < .05$.
** $p < .01$.

3. Results

3.1. Habituation task

Infants' looking varied depending on stimulus complexity (see Table 2 for the descriptive data). Peak look for habituation trials with complex stimuli ($M = 1.09$, SD = .33) was significantly longer than for simple stimuli ($M = .92$, SD = .26; $t(70) = -3.62$, $p = .001$, *B*Ca 95% CI [−0.26, −0.08]). Thus, colourful, crowded scenes were more difficult and required longer looking than simple geometrical shapes.

3.2. Chaos as predictor of infant looking

We used hierarchical regression analyses to test the associations between family SES, chaos and infant looking durations. Separate regressions were run for dependent variables of peak look duration for simple and complex stimulus conditions of the habituation task. See Table 4 for regression coefficients. Preliminary correlation analyses (see Table 3) did not reveal any significant correlations of looking durations with participant age, birthweight or gestational age (all *r*s < .105, all *p*s > .38), while maternal age showed borderline significant correlation with peak look duration for complex stimuli ($r = .24$, $p = .047$).

3.2.1. Complex stimuli

In the first step we entered family income and two control variables: maternal state anxiety, infant low sensory threshold. The model did not reach significance level ($R^2 = .08$, $F[3,67] = 2.03$, $p = .12$). Infants with higher scores on low threshold looked longer at complex stimuli ($\beta = .25$, $t = 2.09$, $p = .041$). Income and maternal anxiety measured before the experiment did not predict infant looking (both *p*s > .45).

In the second step we entered our last predictor–chaos scores. They were positively associated with peak look duration for complex stimuli ($\beta = .26$, $t = 2.18$, $p = .033$) and explained additional 6% of variance ($\Delta R^2 = .061$, $F_{change}[1,66] = 4.74$, $p = .033$). Maternal anxiety and income did not predict peak look duration (both *p*s > .23), while the association between higher scores for low sensory threshold and longer look duration was approaching significance ($\beta = .23$, $t = 1.91$, $p = .061$). The overall model explained nearly 15% of variance in infant look duration for complex stimuli ($R^2 = .145$, $F[4,66] = 2.80$, $p = .033$).

3.2.2. Simple stimuli

Regression coefficients are presented in Table 4. None of the entered variables predicted infant looking at simple stimuli neither in the first step ($R^2 = .04$, $F[3,67] = 1.02$, $p = .39$) nor in the second step ($R^2 = .06$, $F[4,66] = 0.99$, $p = .42$).

3.2.3. Interactions of chaos with sex and sensory thresholds

Additional exploratory regression analyses did not reveal any effects of participant sex on infant looking or interactions of participant sex or sensory thresholds with chaos. Similarly, the inclusion of maternal age in Step 1 of the regression model did not reduce the effect of chaos on infant looking in Step 2, hence maternal age was dropped from regression analyses (see Supporting Information).

3.3. Indirect measures of crowding as predictors of infant looking

The number of family members residing together at home and the number of children at home can be considered as indirect measures of crowding. We used both these measures to further test whether crowding as a specific dimension of physical home environment also selectively predicts infant looking durations for complex but not for simple stimuli. Preliminary correlation analyses indicated that chaos was significantly correlated with both the number of children ($r = .31$, $p = .01$), and the number of family members ($r = .25$, $p = .038$). Both these measures were highly correlated with each other ($r = .80$, $p < .001$), while they

Table 4
Regression coefficients for peak look duration in the habituation task with simple and complex stimuli. Unstandardized (B) and standardized (β) regression coefficients with Standard Error (SE). Significant results are indicated with an asterisk: .

Predictor	Simple stimuli					Complex stimuli				
	B	SE	*β*	*B* CI 95%		*B*	SE	*β*	*B* CI 95%	
				Low.	Upp.				Low.	Upp.
Step 1										
Maternal anxiety	−.01	.00	−.15	−.01	.01	.00	.01	−.09	−.02	.01
Low threshold	.00	.01	.10	−.01	.01	.01	.01	.25*	.00	.02
Income	−.05	.07	−.08	−1.19	.09	.01	.08	.02	−.16	.01
R^2	.04					.08				
Step 2										
Maternal anxiety	−.01	.01	−.17	−.02	.00	−.01	.01	−.14	−.02	.00
Low threshold	.00	.01	.09	−.01	.01	.01	.01	.23†	.00	.02
Income	−.04	.07	−.07	−.18	.10	.03	.08	.04	−.14	.19
Chaos	.19	.20	.12	−.21	.59	.51	.24	.26*	.04	.98
ΔR^2	.01					.06*				
R^2	.06					.15*				

Significant results are indicated with an asterisk:
† $p < .1$.
* $p < .05$.

were also significantly correlated with peak look duration for complex (number of children and number of family members, respectively: $r = .35$, $p = .003$; $r = .43$, $p < .001$), but not for simple stimuli (respectively: $r = .13$, $p = .28$; $r = .15$, $p = .21$).

We further tested whether these indirect measures of crowding significantly predict infant looking. We used the same regression model as previously, but replaced chaos as predictor in Step 2 with the number of family members. Step 1 remained the same as in previous analyses, thus it is not reported here.

3.3.1. Complex stimuli

Number of family members added in the second step was positively associated with peak look duration for complex stimuli ($\beta = .52$, $t = 4.11$, $p < .001$) and explained additionally nearly 19% of variance ($\Delta R^2 = .187$, $F_{change}[1,66] = 16.90$, $p < .001$). Maternal anxiety and low sensory threshold did not predict peak look duration (both $ps > .13$), but family income did ($\beta = -.29$, $t = 2.33$, $p = .023$). The overall model explained 27% of variance in infant look duration for complex stimuli ($R^2 = .270$, $F[4,66] = 6.10$, $p < .001$).

3.3.2. Simple stimuli

None of the entered variables predicted infant looking at simple stimuli in the second step ($R^2 = .045$, $F[4,66] = 0.78$, $p = .55$).

4. Discussion

The main goal of our study was to investigate whether chaotic home environment is associated with stimulus processing during a habituation task in early infancy. The results provide evidence for a potential new causal mechanism linking the quality of home environment and infant visual processing, but only under higher task demands. The level of household chaos predicted the time that 5.5-month-olds spent processing complex visual scenes. Greater reported chaos was associated with longer looking, that is, slower processing of complex stimuli. No such association was found for simple, unattractive visual stimuli. The two habituation conditions markedly differed in feature congestion and visual complexity, rendering the condition with complex stimuli significantly more difficult. Altogether, we found evidence for decreased processing speed of young infants from more chaotic homes, but only when the task required greater cognitive resources.

Since household crowding is closely related to the construct of chaos (Matheny et al., 1995; Wachs et al., 1990), we predicted a similar association between reduced processing speed under higher task demands and greater number of family members residing at home. Additional regression analyses fully confirmed our predictions, showing that the greater number of people residing at home was significantly associated with lower processing speed in the complex, but not the simple stimulus condition. Moreover, this secondary, indirect measure of crowing explained nearly 19% of variance in infant peak look duration, further validating and strengthening our main results. Although early stressors may differentially affect boys and girls (Hernández-Martínez, Arija, Escribano, & Canals, 2010), we did not find any interaction between chaos and participant's sex. This suggests that in our sample boys and girls were similarly affected by household chaos.

Our results are further strengthened by the fact that the effects of chaotic home environment were observed over and above the effects of infant sensory thresholds. Individual differences in reactivity to novel stimulation is related to the rate of familiarization in 7-month-olds (Vonderlin, Pahnke, & Pauen, 2008). This temperamental dimension is closely associated with Low Threshold subscale of the Infant/Toddler Sensory Profile (DeSantis et al., 2011). Thus, we investigated whether the effects of chaotic home environment influenced infants' processing speed over and above the effects of infant sensory thresholds. Consistent with these reports we found that lower sensory threshold was significantly associated with longer looking at complex, but not simple stimuli. This may suggest that sensory reactivity is related to infant habituation speed in infants as young as 5.5 months. One potential explanation of this result is that the level of stimulation in the complex task was too high for infants with low sensory thresholds. In consequence, such overstimulation may have lead to over-arousal and avoidance of processing. Thus lower sensory thresholds may affect infant processing speed similarly to household chaos (see below).

Importantly, additional exploratory analyses did not show any interaction between sensory threshold and chaos, suggesting that these factors are independently related to infant processing speed. We note, however, that the internal consistency of the Low Threshold subscale may have been insufficient to reliably measure this aspect of sensory processing. Therefore, these results need to be interpreted with caution. Further research is necessary to better understand the associations between sensory thresholds, speed of processing and their interactions with infant's physical environment.

Apart from sensory thresholds we also controlled for maternal state anxiety, which was measured with a popular standardized State Trait Anxiety Inventory (Spielberger et al., 1983). Contrary to our predictions we did not find any effect of maternal self-reported anxiety just before the procedure on infant habituation times in either condition. This may suggest that even when the infant is seated on the mother's lap, the habituation task itself is a mild stressor that does not affect maternal behaviour.

Evans et al. (2009) suggest that chaos is harmful to children's development because it interferes with proximal process, a term introduced by Bronfenbrenner in his bioecological model (Brofenbrenner & Morris, 2006). In other words, the increasingly complex interactions of the child with his or her immediate environment become less effective due to disruptions and reduced predictability. Below we outline two likely explanations of our results: the effects of chaos on infant's readiness to attend to stimuli and on the development of attention regulation during infant-parent interactions.

Chaotic home environment involves crowded space, noise and confusion (Matheny et al., 1995). All these factors contribute to a less favourable learning environment, where there could be too many intense stimuli to process, resulting in lower signal-to-noise ratio and reduced salience of stimuli the infant prefers to attend. Overstimulation, noise and unpredictability may lead the infant to experience prolonged periods of high arousal and vigilance (see e.g. Obradović, 2012). Consistent with some models of visual attention high vigilance may lead to the shortening of individual fixations and decreased ability to engage attention with task-relevant stimuli for long enough to ensure full processing (Aston-Jones, Rajkowski, & Cohen, 1999). Highly vigilant infants are more likely to exogenously orient to perceptually salient distractors, than to endogenously orient in line with their internal goals and interests (de Barbaro, Chiba, & Deák, 2011). Thus, chaos may hinder the processing of complex stimuli by attenuating the development of selective attention mechanisms.

The second explanation of our data draws on research demonstrating the role of early infant-parent interactions for young infants' emerging attention control and self-regulatory skills (see e.g. Feldman, 2007). Firstly, infants react to overstimulation with fussing or even persistent crying (James-Roberts, Conroy, & Wilsher, 1998), and when highly vigilant, they show reduced attention to people (de Barbaro et al., 2011). Secondly, young infants rely on their parents to help them to effectively attend to objects (especially those less salient), sustain attention on those objects and later disengage attention. For example, longer episodes of mutual gaze between the infant and the parent at 5.5 months of age predict better attention disengagement at the age of 11 months (Niedźwiecka et al., in press).

Osório, Martins, Meins, Martins, and Soares (2011) showed that strategies that mothers use to regulate attention of 10-month-olds (entertaining, bids for joint attention, teaching) are associated with their infants' joint attention skills. For instance, entertaining, i.e. animating a toy or playfully touching the child with a toy, is positively associated with parallel attention (mother and infant looking at the same object); the number of maternal bids for joint attention is positively correlated with the number of infant responses and fewer teaching behaviours increase the likelihood that the infant initiates joint attention.

Chaotic environment may disrupt the sequences of parental interactions with the infant and in consequence have negative impact on his or her emerging attentional skills. This is illustrated by research from families with low SES, where 9 month-olds benefited from directive maternal behaviours, such as introducing an object, maintaining infant's attention on the object or redirecting attention (Mendive, Bornstein, & Sebastián, 2013) whereas a non-directive style is considered optimal in middle or high SES samples (see e.g. Aldred, Green, & Adams, 2004; Wan et al., 2012). Further research is necessary to test whether similar mechanisms could drive the effects of chaotic home environment we have found in 5.5-month-old infants.

While we consider our study a step forward in showing the mechanisms by which early adversity may diminish infant cognitive resources at an early age, our results are not free from limitations. Firstly, we conducted the study on a sample of predominantly middle-class families, with reduced SES variability. Such approach has been used previously to isolate chaos-specific effects on cognitive development (see Evans et al., 2009), but it prevented us from directly testing the interactions between SES and chaos. While low SES and high household chaos often co-occur, there is strong evidence that they act as independent predictors of cognitive development or that SES effects are mediated by chaos (Chen et al., 2010; Evans et al., 2005; Shelleby et al., 2014).

Finally, our conclusions are necessarily limited by the correlational nature of the study and its relatively short time perspective. While the effects of adverse environment normally emerge gradually throughout the first years of life (Noble, Houston, Kan, & Sowell, 2012), recent infant research shows that some effects can be detected prior to the first birthday. Hence the early association between chaos and slower processing speed for complex stimuli is consistent with a host of recent reports on the presence of SES-related differences in brain structure (Hair, Hanson, Wolfe, & Pollak, 2015; Hanson et al., 2013) and function (Tomalski et al., 2013) and cognitive capacities before the first birthday (Clearfield & Jedd, 2013; Clearfield & Niman, 2012; Clearfield, Stanger, & Jenne, 2015; Tucker-Drob, Rhemtulla, Harden, Turkheimer, & Fask, 2011). Further research is necessary to delineate specific developmental trajectories that link early adverse environment with these emerging differences in neurocognitive functioning.

5. Conclusions

We found evidence for likely detrimental effects of household chaos and crowding on young infants' processing speed under high task demands. No such effect was found for visual processing of simple, undemanding stimuli. Our results likely highlight the role of interactions with both physical and social environment in shaping early infant attentional development.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.infbeh.2017.04.007.

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