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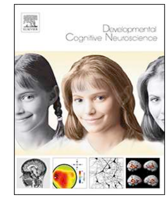

Longitudinal associations among family environment, neural cognitive control, and social competence among adolescents

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ABSTRACT

During adolescence, prefrontal cortex regions, important in cognitive control, undergo maturation to adapt to changing environmental demands. Ways through which social-ecological factors contribute to adolescent neural cognitive control have not been thoroughly examined. We hypothesize that household chaos is a context that may modulate the associations among parental control, adolescent neural cognitive control, and developmental changes in social competence. The sample involved 167 adolescents (ages 13–14 at Time 1, 53% male). Parental control and household chaos were measured using adolescents' questionnaire data, and cognitive control was assessed via behavioral performance and brain imaging at Time 1. Adolescent social competence was reported by adolescents at Time 1 and at Time 2 (one year later). Structural equation modeling analyses indicated that higher parental control predicted better neural cognitive control only among adolescents living in low-chaos households. The association between poor neural cognitive control at Time 1 and social competence at Time 2 (after controlling for social competence at Time 1) was significant only among adolescents living in high-chaos households. Household chaos may undermine the positive association of parental control with adolescent neural cognitive control and exacerbate the detrimental association of poor neural cognitive control with disrupted social competence development.

The developmental period of adolescence is characterized by dramatic changes in the brain (Casey et al., 2008). In particular, prefrontal cortex regions, important in cognitive control (CC), have been shown to undergo maturation, including increased myelination and experience-dependent synaptogenesis and pruning (Paus, 2005) as well as strengthening of connections within prefrontal circuitry to adapt to changing environmental demands (Liston et al., 2006) throughout adolescence and into early adulthood. Neurodevelopmental models of adolescent motivated behavior (Casey et al., 2008; Ernst et al., 2006) suggest that subcortical "emotional/motivational" regions develop earlier in adolescence than prefrontal "cognitive control" regions, explaining why adolescence is a period when self-control becomes particularly difficult.

Self-control refers to the ability to inhibit certain emotions, thoughts, or actions and to feel, think, or act in alternative, more appropriate ways in the pursuit of long-term goals (Baumeister et al., 2007; Casey, 2015). The social environment is thought to have an important influence on the development of self-control during adolescence (Casey, 2015). We incorporate a *bioecological model* (Bronfebrenner and Morris, 1998) as a theoretical basis for examining how socio-ecological factors are associated with CC and social competence in adolescence. The bioecological model defines "proximal processes" as interactions between the organism and the environment that serve as the primary mechanisms influencing human development, and emphasizes that the influence of such processes varies systematically as a function of the environmental *context*. In the present study, we examined the role of household chaos as a context that modulates the associations among parental control, adolescent neural CC, and developmental changes in social competence.

Within the bioecological model, 'chaotic systems'—characterized by frenetic activity, lack of structure, and unpredictability in everyday activities—are regarded as a major source of interruption of proximal processes that engender competence (Bronfenbrenner and Evans, 2000). Past research has demonstrated that the level of chaos, defined as confusion, clutter, and ambient noise in the home, is an important aspect of family dynamics that interferes with optimal parenting

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practices and could subsequently impact developmental outcomes (Evans and Wachs, 2010 for review). There is an increasing body of evidence documenting household chaos as a contextual factor that alters the effects of parenting. For example, during early to middle childhood, the association between poor quality parent-child relationships (e.g., low positivity, harsh discipline) and children's behavior problems is exacerbated in the context of high household chaos (Asbury et al., 2003; Coldwell et al., 2006). In addition, during adolescence, reactive and harsh parenting styles predict more callous-unemotional traits in high but not low chaos environments (Kahn et al., 2016). These findings suggest that household chaos may function as a moderator between parenting and children's adjustment. According to the bioecological model (Bronfenbrenner and Morris, 1998), higher parental control may be a positive proximal process, which is associated with higher adolescent self-control. Yet this association may be disrupted by the *context* characterized by high household chaos.

Within neuroscience literature, prior research has shown that positive parenting behaviors (e.g., warmth) and positive parent-child relationships (e.g., high emotional support and low conflict) are related to longitudinal changes in prefrontal brain structure (e.g., accelerated thinning in the anterior cingulate and orbitofrontal cortices; Whittle et al., 2014) as well as reward-related neural activity during risk taking (e.g., decreased activation in ventral striatum; Qu et al., 2015). In contrast, negative family relationships (e.g., high conflict and low cohesion) seem to impede development in the prefrontal regions which subserve CC (e.g., increased activation in ventrolateral prefrontal cortext; McCormick et al., 2016). To date, however, no empirical study has examined the effects of parental control on prefrontal functioning related to CC. Therefore, we sought to address this gap by examining one of the parental monitoring features that seems to be critical for self-control development: *parental control*, which represents the active supervision and establishment of clear expectations and boundaries for youth (Stattin and Kerr, 2000).

The importance of parental control in the development of self-control is emphasized by the self-control theory (Gottfredson and Hirschi, 1990). According to this theory, high self-control is fostered by effective socialization by parents (e.g., teaching their children to think about the long-term consequences of their acts) and low control is produced by the absence of nurturance, discipline, or training. For the effective socialization, parents must monitor their children's behaviors; recognize deviant behaviors when they occur; and punish such behaviors (Gottfredson and Hirschi, 1990). Thus, parents' adequate control over children's behaviors is critical for optimal self-control development. Extant literature suggests that higher parental control is related to higher self-control among their adolescent children (Bowers et al., 2011; Farley and Kim-Spoon, 2017; Ng-Knight et al., 2016; but see Finkenauer et al., 2005). Parental control may promote adolescent self-control by increasing adolescents' awareness of being monitored, thus making them more conscious of their behaviors as well as possible consequences of their behaviors.

Researchers have paid increasing attention to the role of impaired CC as a risk factor in the development of psychopathology and risk taking (see Crone et al., 2016 for review), but we do not know whether and how CC is associated with positive adaptation. Throughout adolescence, competence is expected to improve as young people mature and learn across multiple domains of adaptation in basic capabilities and coordinated execution of actions (Masten, 2007). Success in social relationships is one of the age-salient developmental tasks during the adolescent period (Masten, 2007), characterized by increased importance and complexity of peer relationships and an improved understanding of others (Blakemore, 2008). The literature suggests that self-control develops in the context of social relationships, and those who demonstrate more self-control maintain higher quality social relationships (Farley and Kim-Spoon, 2014 for review). For example, children and adolescents who are better able to behaviorally self-regulate are also more socially competent (McKown et al., 2009). Similarly, young adults with better emotion regulation abilities tend to be more sensitive to others and engage in more prosocial activities; consequently, they receive greater positive nominations from peers (Lopes et al., 2005). Finally, in a recent longitudinal study spanning middle childhood through middle adolescence, higher levels of executive functions (measured by inhibitory control, attention, and working memory) reduced the likelihood of experiencing problems in peer relationships later on (Holmes et al., 2016). According to the bioecological model, *person* (i.e., the characteristics of the organism) can directly shape proximal processes. It follows that high self-control would facilitate forming positive social relationships, thus promoting high social competence. Yet this association may be disrupted by the *context* characterized by high household chaos.

In the current study, we examined socio-ecological factors that are associated with the neural CC system in adolescence. We focused on how parenting behavior and home environment may be related to the neural CC system which in turn is related to changes in social competence. Specifically, we examined the role of household chaos as a contextual factor that modulates (1) the association between parental control and the neural CC system, and (2) the association between the neural CC system and the development of social competence. Given that brain development during adolescence is expected to be influenced by both biological factors, such as puberty (Blakemore et al., 2010; Crone and Dahl, 2012), as well as experience-dependent plasticity that varies with environmental contexts, we also examined the effects of pubertal development on CC.

1. Methods

1.1. Participants

Participants were 167 adolescents (53% male) aged 13–14 years at Time 1 ($M = 14.13$, $SD = 0.54$) or 14–15 years at Time 2 ($M = 15.05$, $SD = 0.54$). About 80% were White, 13% were African American, and 7% were in other racial groups. The median of family annual income ranged from $35,000 to $49,999 at both time points. The sample was representative of the region of the state for household income and race/ethnicity. At Time 1, 157 adolescents participated in the study. At Time 2 (approximately one year later), 17 adolescents did not return for the following reasons: ineligibility for tasks ($n = 2$), declined participation ($n = 7$), and lost contact ($n = 8$). Ten additional adolescents were invited to participate at Time 2, leading to the final sample of 167 adolescents. Multiple logistic regression analyses indicated that attrition was not significantly predicted by demographic (age, income, race, sex) and most study variables (household chaos, parental control, pubertal development, neural and behavioral CC, all $ps > 0.215$). However, adolescents that did not return for Time 2 had lower social competence at Time 1, compared to adolescents that did return ($p = 0.028$). Adolescents were excluded from participation if they had a history of head injury resulting in loss of consciousness for more than 10 min, claustrophobia, orthodontia impairing image acquisition, or contraindications to magnetic resonance imaging.

1.2. Procedure

Participants were recruited by diverse advertisement methods including flyers, recruitment letters, and e-mail distributions. Data collection took place at the university offices where adolescents and their primary caregivers were interviewed by trained research assistants. All adolescents provided written assent and their parents provided written permission for a protocol approved by university's institutional review board.

1.3. Measures

1.3.1. Parental control

Adolescents reported on their parents' monitoring practices at Time 1 using the 6-item parental control subscale of the Parental Monitoring Scale (Stattin and Kerr, 2000). The items measure the extent to which parents require their adolescents to ask permission and to inform them about their social activities (e.g., "If you have been out very late one night, do your parents require that you explain what you did and whom you were with?"). Response options range from "1 = Yes, always" to "5 = No, never." Items were recoded so that higher scores indicated higher parental control and averaged into an overall parental control score. The scale showed a good reliability (α = 0.83) in the present sample.

1.3.2. Household chaos

Adolescents reported on the level of household chaos at Time 1 (i.e., level of confusion and disorganization in the home) using the 6-item Confusion, Hubbub, and Order Scale (CHAOS; Matheny et al., 1995). An example item is "You can't hear yourself think in our home." Response options range from "1 = Definitely untrue" to "5 = Definitely true." Mean scores were calculated with higher scores indicating higher levels of household chaos. The reliability of the scale was relatively low in the present sample (α = 0.59), which is consistent with prior research which has demonstrated reliable predictive and construct validity of this scale (e.g., Asbury et al., 2003; Coldwell et al., 2006).

1.3.3. Social competence

Adolescents' social competence was measured using the social competence scale from the Youth Self Report (Achenbach and Rescorla, 2001). The scale targets adolescent participation in organizations, and asks about the number of activities, frequency of participation, and competence in each organization. It also targets the number of friends and time spent with friends as well as how well the adolescent gets along with siblings, peers, and parents. *T*-scores were used with higher scores indicating greater social competence. The scale demonstrated relatively low internal consistency in the present sample (α = 0.52 at Time 1, α = 0.50 at Time 2), which is consistent with previous research (Achenbach and Rescorla, 2001).

1.3.4. Pubertal development

Pubertal development was assessed using adolescents' reports on the 5-item Pubertal Development Scale (Petersen et al., 1988). Adolescents answered questions about their growth spurt, body hair, and skin changes. Additionally, female adolescents reported on their breast development and their menarche and male adolescents on voice and facial hair changes. Responses were given on a four-point scale ranging from "1 = No changes" to "4 = Changes completed." An overall index of pubertal development status was calculated by averaging the items, with higher scores indicating more advanced pubertal development status.

1.3.5. Cognitive control (CC)

We measured detection and response to conflict associated with both flanker and spatial interference using the Multi-Source Interference Task (MSIT; Bush et al., 2003, see Fig. 1a). The MSIT requires participants to indicate which of three numbers is different from the other two. In neutral conditions, target numbers were congruent with the numbers' presented locations. In interference conditions, target numbers were incongruent with the target locations (e.g., 2 was in the third position). Consistent with previous reports (Bush et al., 2003), we found a significant MSIT interference effect (i.e., main effect of congruency) in both measures of task performance: accuracy, $t(153) = -15.47$, $p < 0.001$, and reaction time for correct responses, $t(153) = 69.58$, $p < 0.001$. We conducted confirmatory factor analyses in which standardized accuracy and reaction time difference scores (interference minus neutral trials) were loaded on a latent behavioral factor score, with higher scores indicating higher CC. Factor loadings were constrained to be equal for model identification purposes. In this fully saturated model ($\chi^2 = 0$, $df = 0$), both factor loadings were significant (0.69, $p < 0.001$).

1.3.6. Imaging acquisition and analysis

We assessed hemodynamic correlates of CC during MSIT completion. Functional images were acquired using a 3.0T Siemens Tim Trio with the following parameters: echo-planar imaging, gradient recalled echo; repetition time (TR) = 2 s; echo time (TE) = 30 ms; flip angle = 90°; 34 axial slices, 4.0 mm slice thickness, 220 × 220 mm field of view (FOV), voxel size = 3.4375 × 3.4375 × 4 mm (during analysis the images were resliced so that voxels were 3 × 3 × 3 mm), 64 × 64 grid, and hyperangulated slices acquired at 30° from the anterior commissure posterior commissure line. The structural scan was acquired using a high-resolution magnetization prepared rapid acquisition gradient echo sequence (TR = 1200 ms, TE = 3.02 ms, FoV = 245 × 245 mm, 1 mm slice thickness, 192 slices with spatial resolution of 1 × 1 × 1 mm). Data were processed and analyzed using SPM8 (Wellcome Department of Imaging Neuroscience, London, UK). Functional images were corrected for head motion using a six-parameter rigid-body transformation, realigned, and normalized to the template space before smoothing. Images were then realigned and normalized to the Montreal Neurological Institute (MNI) template using parameters derived from a segmented anatomical image coregistered to the mean EPI and were spatially smoothed using a 6 mm full-width at half-maximum Gaussian kernel. As described below, general linear models were specified for each participant and subsequent second level random effects analyses were conducted.

For each participant, individual-level regions-of-interest (ROI) values were extracted at coordinates corresponding to peak activations in the interference minus neutral second-level contrast (see Table 1). Specifically, the first eigenvariate values of the contrast images were extracted using spherical masks of 5 mm surrounding MNI coordinates, thresholded at $p < 0.001$, family-wise error corrected. Among these extracted ROI values, variables representing (1) regions known to be engaged by CC related to interference- and error-processing (Fitzgerald et al., 2010; Koechlin et al., 2003; Roberts and Hall, 2008) and (2) regions significantly correlated with behavioral performance (i.e., absolute magnitude of correlation > 0.2 with the behavioral performance factor score) were chosen as manifest indicators of the neural CC factor. These ROIs included left posterior-medial frontal cortex, right and left inferior frontal gyrus, left and right inferior parietal lobules, right insula, right superior frontal gyrus, and left middle frontal gyrus (see Fig. 1b). Using these ROIs, we conducted confirmatory factor analyses, in which the selected indicators were loaded on an overall neural CC factor. Based on modification indices, we included residual correlations between left and right inferior parietal lobules, right superior frontal gyrus and left middle frontal gyrus, right inferior frontal gyrus and left middle frontal gyrus, and left posterior-medial frontal cortex and right inferior frontal gyrus. The final model showed a good fit ($\chi^2 = 21.34$, $df = 16$, $p = 0.166$, CFI = 0.99, RMSEA = 0.05). Standardized factor loadings ranged from 0.57 to 0.85 (all $ps < 0.001$). This neural CC factor score correlated significantly with the behavioral CC score (−0.46, $p < 0.001$), indicating that higher blood oxygenation-level dependent (BOLD) responses in these regions were associated with lower levels of behavioral CC.

1.4. Statistical analyses

We conducted structural equation modeling analyses using M*plus* 7.4 (Muthén & Muthén, 1998–2015Muthén and Muthén, 1998Muthén & Muthén, 1998–2015) to test our hypothesized moderation model following recommendations by Hayes (2013). The missing data pattern

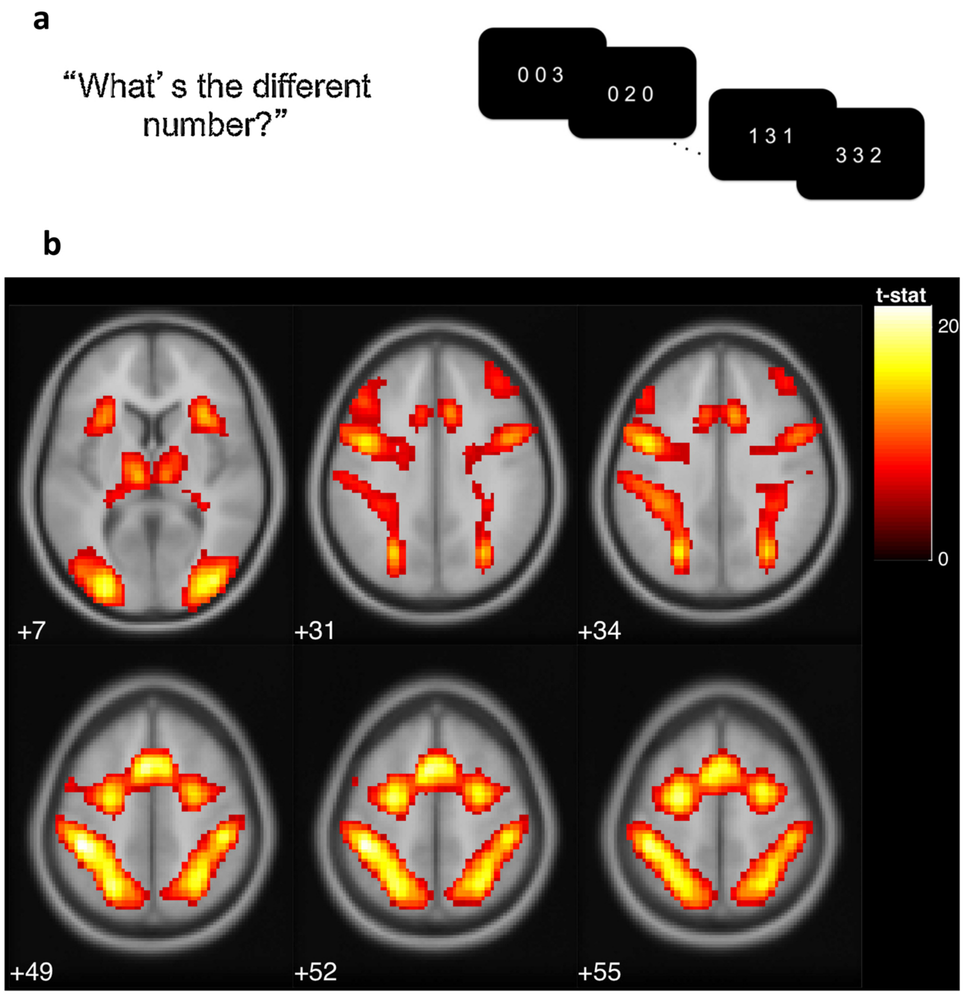

Fig. 1. a) In the multi-source interference task (MSIT), adolescents were asked to identify the digit that differed from two other concurrently presented digits, ignoring its position in the sequence. b) Adolescents exhibited greater activation for interference relative to neutralconditions in the regions of left posterior-medial frontal cortex, right and left inferior frontal parietal lobules, right insula, right superior frontal gyrus, and left middle frontal gyrus, displayed at p(FWE) < 0.001 (see Table 1).

resembled a Missing Completely at Random pattern (Little's MCAR test on all study variables: $\chi^2 = 34.93$, $df = 27$, $p = 0.141$). Therefore, we used Full Information Maximum Likelihood (FIML) estimation with robust standard errors (MLR) to account for missing data and non-normal distributions. As can be seen in Fig. 2, we tested the effects of parental control at Time 1 on neural CC at Time 1 as well as social competence at Time 2, and the effects of neural CC at Time 1 on social competence at Time 2. The effect of social competence at Time 1 on social competence at Time 2 was controlled for. The effects of pubertal status at Time 1 on neural CC at Time 1 were also estimated. We tested moderating effects of household chaos for the following three paths: a) parental control at Time 1 → neural CC at Time 1, b) neural CC at Time 1 → social competence at Time 2, and c) parental control at Time 1 → social competence at Time 2. In order to do so, we calculated interaction terms (based on mean-centered scores) between parental control at Time 1 and household chaos at Time 1 for paths a) and c); and between neural CC at Time 1 and household chaos at Time 1 for path b). The main effects of household chaos at Time 1 on neural CC at Time 1 and social competence at Time 2 were also estimated. Simple slope analyses were calculated for significant moderation effects (contrasting 1 *SD* below the mean and 1 *SD* above the mean).

2. Results

Prior to analyses, seven outlier scores that deviated more than 3 *SD* from the mean were winsorized to the next value that was not an outlier. Descriptive statistics of study variables can be found in Table 2. The hypothesized model showed an acceptable fit: $\chi^2(3) = 6.09$, $p = 0.107$, CFI = 0.93, RMSEA = 0.08. As shown in Fig. 2, results indicated that household chaos significantly moderated the effects of parental control at Time 1 on neural CC at Time 1 ($b = 0.14$, $SE = 0.07$, $b^* = 0.16$, $p = 0.037$). There was also an indication that the effects of neural CC at Time 1 on social competence at Time 2, after controlling for the baseline social competence at Time 1, may vary depending on household chaos ($b = -4.24$, $SE = 2.17$, $b^* = -0.14$, $p = 0.050$). However, household chaos did not significantly moderate the effects of parental control at Time 1 on social competence at Time 2 ($b = -1.42$, $SE = 1.43$, $b^* = -0.07$, $p = 0.319$).

Simple slope analyses for the moderation effect of household chaos are depicted in Fig. 3. Results indicated that higher parental control at Time 1 was significantly associated with lower interference-related BOLD responses (i.e., higher CC) at Time 1 for low levels of household chaos ($b = -0.20$, $SE = 0.08$, $b^* = -0.34$, $p = 0.011$), but not for high levels of household chaos ($b = -0.01$, $SE = 0.06$, $b^* = -0.02$, $p = 0.889$). In contrast, higher interference-related BOLD responses (i.e., lower CC) at Time 1 were associated with lower social competence at Time 2, after controlling for previous levels of social competence, for high levels of chaos ($b = -4.38$, $SE = 2.16$, $b^* = -0.21$, $p = 0.042$), but not for low levels of chaos ($b = 1.30$, $SE = 2.35$, $b^* = 0.07$, $p = 0.580$). In supplemental analyses, we tested the hypothesized model using *behavioral* CC (instead of *neural* CC). The model showed an acceptable fit: $\chi^2(3) = 6.22$, $p = 0.101$, CFI = 0.91, RMSEA = 0.08.

Table 1
Areas of significant activation for the contrast of Interference minus Neutral blocks of the Multi-Source Interference Task.

Cluster		Peak	MNI Coordinates			Region
k	*p(FWE)*	*t*	*x*	*y*	*z*	
759	**< 0.001**	21.84	−42	−37	49	L postcentral gyrus
		19.61	−24	−64	49	L superior parietal lobule
		18.07	**−30**	**−55**	**52**	**L inferior parietal lobule**
265	**< 0.001**	**20.43**	**−3**	**14**	**49**	**L posterior-medial frontal**
506	< 0.001	20.42	−39	−85	−2	L inferior occipital gyrus
		20.15	−30	−91	−2	L inferior occipital gyrus
		19.05	−39	−73	−8	L fusiform gyrus
654	< 0.001	19.21	42	−64	−8	R fusiform gyrus
		19.17	42	−82	−2	R inferior occipital gyrus
		18.46	33	−91	1	R inferior occipital gyrus
		15.78	39	−67	−23	R cerebellum (crus 1)
		15.24	33	−49	−26	R cerebellum (VI)
245	**< 0.001**	**19.06**	**−24**	**−4**	**55**	**L middle frontal gyrus**
431	**< 0.001**	**18.12**	**30**	**−58**	**52**	**R inferior parietal lobule**
		18.11	45	−31	49	R postcentral gyrus
		16.52	30	−64	40	R superior occipital gyrus
140	**< 0.001**	**17.38**	**27**	**−4**	**55**	**R superior frontal gyrus**
94	**< 0.001**	**16.89**	**−45**	**2**	**34**	**L inferior frontal gyrus (pars opercularis)**
46	< 0.001	15.01	−9	−19	10	L thalamus
24	**< 0.001**	**14.50**	**33**	**20**	**7**	**R insula lobe**
7	< 0.001	13.47	6	−73	−20	Cerebellar vermis (7)
13	**< 0.001**	**13.32**	**48**	**8**	**31**	**R inferior frontal gyrus (pars opercularis)**
12	< 0.001	13.31	−30	17	10	L insula lobe
5	< 0.001	12.73	9	−19	10	R thalamus
9	< 0.001	12.66	−27	−55	−23	L cerebellum (VI)
		12.60	−27	−64	−23	L cerebellum (VI)

Note: Voxel-wise thresholded at $t = 12$, equivalent to $p = 2.00 \times 10^{-23}$ uncorrected. k = the number of voxels in each significant cluster; *FWE* = family-wise error corrected; t = peak activation level in each cluster; x, y, z = MNI coordinates; L = left; R = right. Boldface indicates the regions included in the neural cognitive control factor scores. Reprinted from Kim-Spoon et al. (2016), Behavioral and neural inhibitory control moderates the effects of reward sensitivity on adolescent substance use. Neuropsychologia (91), 318–326.

Results, however, indicated that none of the moderation effects of household chaos was significant (all *ps* > 0.444).

3. Discussion

Our findings supported the moderating role of household chaos in the associations among parenting behavior, adolescent neural functioning, and competence development. Specifically, higher parental control was related to better neural CC among adolescents only in the context of low household chaos. In contrast, poor neural CC was related to compromised development of social competence only in the context of high household chaos. Thus, the positive association between parental control and neural CC was most evident in the absence of chaos, whereas detrimental effects of neurocognitive vulnerability were most prominent in chaotic environments. Taken together, the findings highlight the importance of the socio-ecological context in adolescent cognitive brain development by illustrating how parental control and household chaos can jointly explain individual differences in neural correlates of CC, which are related to the development of social competence during adolescence.

As expected by the self-control theory (Gottfredson and Hirschi, 1990), parental control was positively related to adolescent neural CC. This finding is consistent with previous behavioral research (Kim-Spoon et al., 2014) that showed strong evidence for positive effects of parental monitoring on adolescent self-control. Particularly, parental control may foster adolescent self-control by working as a conduit for transmitting behavioral rules and guidelines and encouraging adolescents to internalize these regulation strategies. Importantly, our findings clarify that such positive associations between parental control and adolescent self-control become substantially diminished when the chaos level is high. Such findings suggest that household chaos may undermine the formation and stability of relationships and activities between parents and adolescents that are essential for parental control to be effective. In support of the bioecological model (Bronfenbrenner and Morris, 1998), our findings illustrate that chaotic home environments have the potential to interfere with the development and maintenance of proximal processes involving parental control with respect to the development of the neural CC system during adolescence.

Researchers have rarely applied the bioecological model to positive developmental outcomes such as social competence. Our findings suggest that adolescents with poor neural CC were likely to show decreases in social competence, particularly in chaotic home environments. The association between neural CC and social competence is expected because flexible CC may promote behavioral exploration in ways that contribute to learning and developing new social-cognitive and social affective skills, ultimately maturing social competence (Crone and Dahl, 2012). Indeed, recent behavioral research demonstrated a longitudinal association between high levels of executive function (based on parent reports and behavioral performance) and low levels of peer rejection and victimization (Holmes et al., 2016). Aside from the direct association between CC and social competence as found in prior studies, the current study clarifies that risky environmental contexts laden with chaos exacerbate the negative association between poor neural CC and problems in the development of social competence among adolescents. We note that the moderating effect of household chaos was evident for the neural indicators of CC but not for the

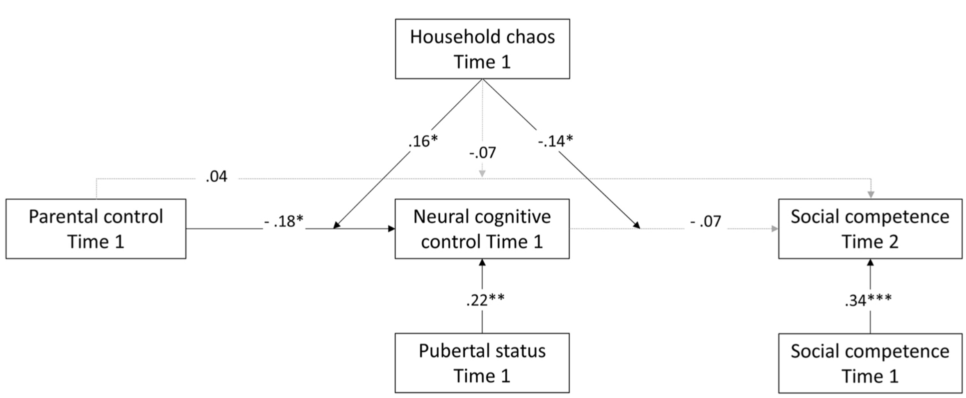

Fig. 2. Summarized model fitting results of the path model of associations among puberty, parental control, neural cognitive control, and social competence moderated by household chaos. Standardized estimates are presented. For the clarity of presentation, the following main effects of household chaos are not presented: b = 0.02, *SE* = 0.06, b* = 0.04, $p = 0.689$ for household chaos at Time 1_ neural cognitive control at Time 1, and b = −3.38, *SE* = 0.99, b* = −0.26, $p = 0.001$ for household chaos at Time 1 _ social competence at Time 2. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 2
Descriptive statistics and bivariate correlations of household chaos, parental control, pubertal development, behavioral and neural cognitive control, and social competence among adolescents.

	1	2	3	4	5	6	*M*	*SD*	Min	Max
1. Household chaos Time 1	–						2.44	0.67	1.17	4.00
2. Parental control Time 1	−0.18*	–					4.23	0.67	2.33	5.00
3. Pubertal development Time 1	0.22**	0.02	–				2.89	0.52	1.40	4.00
4. Neural cognitive control Time 1	0.11	−0.16	0.21*	–			0.84	0.39	−0.19	1.87
5. Behavioral cognitive control Time 1	0.00	0.05	−0.11	−0.46***	–		0.01	0.79	−2.20	2.09
6. Social competence Time 1	−0.15	0.14	−0.01	−0.16	0.14	–	47.03	9.00	25.00	65.00
7. Social competence Time 2	−0.33***	0.11	0.08	−0.19*	0.13	0.39***	48.37	8.77	28.00	65.00

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

behavioral indictors of CC. Such a discrepancy may be in part due to the fact that behavior tested using a laboratory task may be limited in representing real-life behaviors, whereas task-related neural responses capture individual differences in neurobiological vulnerability more reliably (Richards et al., 2013).

Within the neuroscience literature, although *age-related* changes in BOLD responses during CC throughout adolescence have been demonstrated (Ordaz et al., 2013), there has been no clear evidence regarding the effects of pubertal status or pubertal timing (i.e., pubertal status for age) on neural functioning related to CC. Our data indicated that adolescents with more advanced pubertal timing showed poorer neural CC ($r = 0.21$, $p = 0.012$). This finding seems to be consistent with the disadvantage of early pubertal timing in mental and behavioral problems (Graber et al., 2010 for review). In contrast, past functional neuroimaging research suggested increased functional maturation of the mentalizing network (e.g., the dorsomedial prefrontal cortex, the right temporo-parietal junction, and the anterior temporal cortex) with the advancement of puberty in girls (Goddings et al., 2012; Klapwijk et al., 2013). Mentalizing enables one to understand another person's intentions and emotions, and is thus considered to be a crucial capacity for a range of social behaviors (Goddings et al., 2012). Further research is warranted to test differential roles of puberty in brain development in

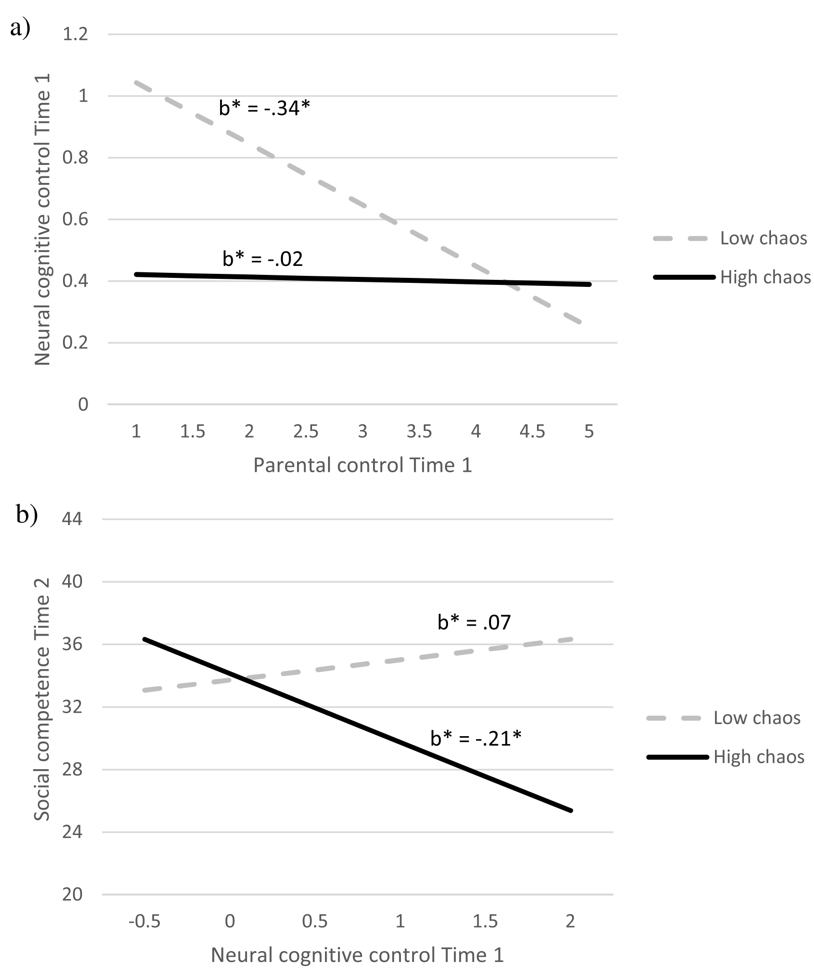

Fig. 3. Simple slope analyses for household chaos moderation results. Standardized estimates are presented. High values of neural cognitive control (i.e., high BOLD interference-related signal during MSIT task) indicate low cognitive control. Social competence Time 2 is controlled for social competence Time 1. a) Simple slope analyses comparing the relation between parental control and neural cognitive control for adolescents with low and high levels of household chaos. b) Simple slope analyses comparing the relation between neural cognitive control and changes in social competence for adolescents with low and high levels of household chaos. *$p < 0.05$.

adolescence: pubertal advancement in general may promote functional maturation of the social brain network, whereas early pubertal timing may hinder functional maturation of the CC network.

Findings from the current study should be interpreted in the context of study limitations. First, our correlational analyses do not allow us to infer causality in the identified relationships. Second, we measured parental control, household chaos, and adolescent social competence based solely upon adolescents' self-reports. Consequently, associations among the variables might have been inflated artificially by method variance due to single informant or mono-method bias. Using data from multiple informants (e.g., parents, peers, and teachers) and multiple methods (e.g., observation and interview) might be worthwhile for future research. Finally, we primarily focused on examining whether interactions between family socio-ecological variables (parental control and household chaos) and pubertal status predict adolescent neural CC. We acknowledge, however, that there are other important biological, environmental, and social relationship factors (e.g., genetic factors, other parenting variables such as warmth and autonomy support, and peer influences) that contribute to the neural development of CC.

In conclusion, the current prospective longitudinal study is the first to show a transactional process by which a stressful, unpredictable home environment challenges frontal cortex functioning during early adolescence—a time in development when neurobiological systems in the brain are reorganizing as part of pubertal development (Blakemore et al., 2010). The findings highlight the important role played by socio-ecological factors in adolescent neurocognitive development. Furthermore, the finding that household chaos can modulate the links between parental control, adolescent CC, and social competence informs prevention and intervention. Household and neighborhood chaos, though correlated with other aspects of socioeconomic risk, can be modified through effective intervention with families and through government policies that reduce uncertainty and distractions in adolescents' environments (Evans and Wachs, 2010).

Conflict of interest

None.

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