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Cognitive flexibility mediates the association between early life stress and habitual behavior

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ABSTRACT

Accumulating evidence suggests that exposure to high levels of early life stress (ELS) may lead to a lasting shift between goal-directed and habitual behavioral tendencies. Cognitive flexibility has been shown to be impaired following early life stress and represents a protective factor for the formation of rigid maladaptive behavior, however, whether cognitive flexibility mediates their association is not clear. Against this background we employed a mediation approach in a sample of n = 560 young healthy Chinese to determine whether cognitive flexibility mediates the association between ELS and habitual behavioral tendencies as assessed by the Creature of Habits Scale (COHS). We present and validate a Chinese version of the COHS (COHS-C) and replicate the two factor solution of the original version. Higher ELS exposure was associated with higher habitual behavioral tendencies and lower cognitive flexibility. Importantly, the association between ELS and habitual behavior was fully mediated by cognitive flexibility, suggesting that ELS-associated deficient cognitive flexibility promotes habitual behavioral tendencies in everyday life. Early intervention approaches that aim at promoting cognitive flexibility may increase resilience for dysregulated habit formation following ELS in adulthood.

1. Introduction

Humans undergo prolonged periods of physical and mental development allowing them to adapt to challenging and complex environments. Together with genetic factors experiences during early sensitive periods lay the foundation for both, adaptive as well as maladaptive behavior during later adulthood. Adverse early life experiences such as childhood neglect or maltreatment can have lasting effects on cognition and behavior in later life (Sonuga-Barke et al., 2017). Accumulating evidence from different lines of research suggests that exposure to early life stress (ELS) associates with lower dispositional trust (Wu et al., 2020), more aggression (Simpson et al., 2012), more suicidal ideation (Puzia et al., 2014) and a strongly increased risk for the development of psychiatric disorders including anxiety, substance use and personality disorders during adulthood (Bonapersona et al., 2018; Teicher et al., 2016; Teicher & Samson, 2016; Ten Have et al., 2019). Overarching theories have argued that the ELS-associated alterations may represent adaptations that promote survival in a malevolent environment (e.g. Gibb et al., 2009; Teicher et al., 2016; Teicher & Samson, 2016). For instance, faster automatic responses, elevated anxious arousal or lower trust may help to avoid harm in the context of childhood maltreatment, however, can become maladaptive during later adulthood and promote the development of psychiatric disorders. On the other hand, recently emerging findings from experimental studies have provided convergent evidence for lasting ELS-associated deficits in several cognitive domains with initial suggestions that ELS-associated alterations in implicit and reward-based learning as well as cognitive flexibility may represent a critical developmental pathway for the manifestation of psychopathological problems in later life (e.g. Harms et al., 2018; Sheridan et al., 2018). However, considerable individual variations in the long-term detrimental effects of ELS have been reported, such that even after severe ELS some individuals do not exhibit cognitive impairments or an elevated psychopathological load (Claessens et al., 2011; Daskalakis et al., 2013; Enoch, 2011; Rutter et al., 2012; Sonuga-Barke et al., 2017).

Habits allow automatic responses in routine contexts and may facilitate appropriate responses under situations of limited cognitive capacity, e.g. due to acute or chronic stress. Habits represent learned

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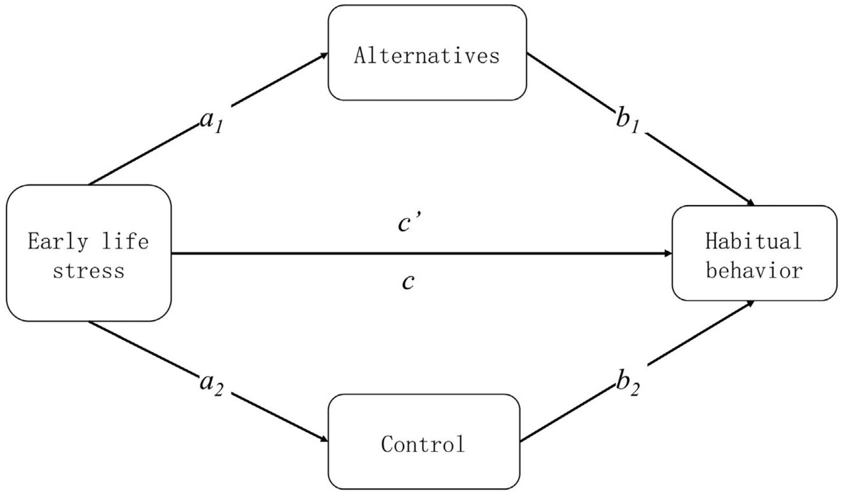

Fig. 1. Hypothesized mediation model between early life stress, cognitive flexibility (two subscales: *alternatives* and *control*) and habitual behavior. Lowercase letters correspond to path coefficients.

behavioral responses that become automatically activated by associated cues or environments after a person repeatedly performs initially goal-directed actions in a specific situation (Wood & Runger, 2016). Across the different research perspectives on habit formation, instrumental and reinforcement learning are considered as key mechanisms that promote the acquisition of habits during the course of repeated responding that ultimately form context- or stimulus-response associations in memory (Harms et al., 2018; Wood & Runger, 2016). The habitual sequence of actions on the behavioral level, or as a mental representation, becomes activated by the corresponding cue or environment and the initially goal-directed behavior becomes under control of the stimulus-response association, rendering the behavior insensitive to changes in the value of the outcome (Harms et al., 2018; Wood & Runger, 2016). Although habits can relieve cognitive load and facilitate fast responses during challenging situations, dysregulated habit formation can promote maladaptive behaviors that are hypothesized to underlie the development and maintenance of substance use disorders or obsessive-compulsive disorder (Everitt & Robbins, 2016; Robbins & Costa, 2017). Given that during the process of habit formation control over behavior gradually shifts away from goal-directed intentions towards associated stimuli, habits are difficult to change even in the context of intentional efforts or knowledge of the negative consequences of habitual actions (Ersche et al., 2016; Wood & Runger, 2016). For instance, in the context of substance use disorders the transition from initial recreational to addictive use has been conceptualized as dysregulated habit formation promoting the transition from initially impulsive substance use to habitual and ultimately compulsive use (Everitt & Robbins, 2016; Zhou et al., 2019). This transition may explain continued drug use despite a lack of pleasurable drug effects and severe detrimental effects.

Substantial experimental evidence suggests that stress induces a shift from goal-directed to habitual behavior (Schwabe & Wolf, 2011), and exposure to ELS strongly increases the likelihood of developing an alcohol or illicit substance use dependence (Bonapersona et al., 2018; Enoch, 2011). Furthermore, neuroimaging studies have demonstrated robust alterations in fronto-striatal circuits in individuals with substance use disorders (Klugah-Brown et al., 2020) and the identified circuits partly overlap with brain systems that mediate habit formation and ELS-induced neural plasticity (Dias-Ferreira et al., 2009; Harms et al., 2018; Teicher et al., 2016; Teicher & Samson, 2016; Uhart & Wand, 2009). A recent study that examined associations between variations in self-reported habitual behavior by means of the newly developed Creature of Habits Scale (Ersche et al., 2017) revealed initial evidence that subjects with higher levels of ELS reported more habitual behavior in daily life as compared to subjects with low adverse early life experiences. Together with a recent experimental study reporting that higher levels of ELS are associated with increased avoidance habits on the behavioral level (Patterson et al., 2019), these findings suggest that ELS could shift the balance between goal-directed and habitual behavior in favor of the latter.

However, the precise pathways by which ELS could induce the shift from goal-directed to habitual behavior remain unclear. On the one hand stronger formation of habits may have beneficial and survival-promoting effects in a malevolent environment, on the other hand it is conceivable that stronger reliance on habits may evolve as a consequence of impaired goal-directed behavior due to chronic stress during early developmental periods. The successful implementation of goal-directed behavior and flexible adaptation to changes in the outcome of behavioral responses requires (among other functions) cognitive flexibility, that is the ability to switch cognitive strategies to adapt to changing environments. High levels of cognitive flexibility have been increasingly demonstrated to be a protective factor that may help individuals to adaptively cope with stressful life events (Murphy et al., 2012). More rigid and less flexible responses have been observed in individuals following exposure to high levels of ELS, such that these individuals had an impaired ability to switch from learned behavioral patterns to new action sequences (Harms et al., 2018).

Against this background the present study examined a mediation model to determine relationships between ELS, cognitive flexibility and habitual behavior in everyday life (Fig. 1). In our model we specified cognitive flexibility as a potential mediator which could mediate the impact of ELS on individual variations in habitual behavior, either partly or totally. According to an overarching theory proposed by (Dennis & Vander Wal, 2010), cognitive flexibility consists of the tendency to perceive situations as controllable, the ability to perceive multiple alternative explanations and the ability to generate multiple alternative solutions when encountering challenging situations. Based on this multi-dimensional nature of cognitive flexibility, the authors developed the Cognitive Flexibility Inventory (CFI), a self-report measure that assesses the three dimensions on separate subscales (Dennis & Vander Wal, 2010). The recently developed and evaluated Creature of Habit Scale (COHS) represents a validated self-report measure to assess individual variations in the extent of habitual behavior in everyday life (Ersche et al., 2017). Importantly, the previous study by Ersche et al. (2017) already showed that individuals with higher ELS exposure reported more habitual behavior in everyday life as compared to subjects with lower ELS exposure.

In line with our hypotheses the aims of the current study were (1) to confirm the reliability and validity of a Chinese version of the COHS

(COHS-C), (2) to investigate whether exposure to early life stress also increases self-reported habitual tendencies in Chinese participants, and (3) to explore whether this association is mediated by cognitive flexibility. Based on the previous literature we formulated a mediation model (Fig. 1) to specifically test the following hypotheses (H):

H1. Higher levels of ELS associate with higher levels of habitual behavior in the Chinese sample (in line with initial findings from Ersche et al., 2017).

H2. Higher levels of ELS associate with lower cognitive flexibility (in line with initial findings from Harms et al., 2018).

H3. Higher cognitive flexibility associates with lower habitual behavior.

H4. The mediation effect of cognitive flexibility on the association between higher ELS and habitual behavior is significant.

2. Methods

2.1. Participants

In line with previous studies on the original Creature of Habit Scale (COHS) (Ersche et al., 2017; Ersche et al., 2019) the assessments were conducted via an online platform (Chinese online survey platform, https://www.wjx.cn). Given that the application of a priori sample size determination in Confirmatory Factor Analysis is still a matter of debate and limited due to methodological shortcomings (see e.g. Kline, 2015; Schreiber et al., 2006) a pragmatical approach for sample size determination was chosen. Sample size estimation in the present study was based on previous studies employing the COHS with samples of N = 362, 533 respectively in the original studies (Ersche et al., 2017; Ersche et al., 2019). All participants were recruited by distributing the link to the online survey to campus life and study related mailing lists and online discussion groups. The link was distributed by members of our research team. A total of N = 647 individuals whose identity remained anonymous, participated in the online data collection. Participants were required to be > 18 years old and Chinese (native-speakers) and free of a current or a history of a mental disorder. Participants from both sexes were included, and no restrictions with respect to employment or relationship status were imposed. As recommended by Meade and Craig (2012) an attention check item was included to identify careless participants. Additional items assessed current or history of mental disorders and medication use to validate the exclusion criteria. 75 participants (12%) were excluded due to either invalid responses on the attention check item or incomplete data. 12 participants (2%) who reported a current or history of a mental disorder or intake of medication were additionally excluded. The final sample for all subsequent analyses consisted of N = 560 participants (38% male) with a mean age of 19.6 years (SD = 1.1). In line with the aims of the present study all participants were administered the COHS-C (details of questionnaires and translation procedure see supplementary material), the Childhood Trauma Questionnaire (CTQ) (Bernstein et al., 2003) and the Cognitive Flexibility Inventory (CFI) (Dennis & Vander Wal, 2010). The study procedures had full approval by the local ethics committee.

2.2. Data analysis

Statistical analyses were conducted using IBM SPSS Statistics Version 23 (IBM Inc., USA) and JASP (Jeffreys's Amazing Statistics Program, https://jasp-stats.org/), an open-source statistical software based on the R package (https://www.r-project.org/). We conducted confirmatory factor analysis (CFA) to verify that the COHS-C structure consists of two latent factors (automaticity and routine) as reported in previous studies (Ersche et al., 2017; Ersche et al., 2019). The χ^2 test, χ^2/df ratio, root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI), goodness-of-fit index (GFI), Tucker-Lewis index (TLI) were used to estimate the construct validity and determine a model fit for the CFA which provides a robust maximum likelihood estimation. Internal consistency reliability of the subscales was assessed by McDonald's omega (McDonald, 2013) and Cronbach's alpha (Cronbach, 1951), with values of more than 0.70 considered as acceptable (Nunnally, 1994).

To avoid a common methodological bias, which leads to common variance due to the measurement method or the instrument - rather than the actual predispositions of individuals that the measurements are thought to examine - we performed Harman's signal factor test on all items of the current study (Podsakoff et al., 2003). In the present study we obtained 13 factors whose eigenvalues were greater than 1, determined by exploratory factor analysis with unrotated factor solution, that totally accounted for 64.38% variances of all variables. The first single factor only accounted for 18.38% variance, which is less than one quarter of the variance in a typical research measure, arguing against the presence of significant measurement errors such as common method bias. Next, we estimated Pearson's correlation coefficients between the major variables in the present study: COHS-C routine and automaticity; CTQ total score; and, CFI alternatives and control. We additionally assessed the hypothesized mediation model (see Fig. 1) to determine the mediation effect of cognitive flexibility (alternatives and control) on the association between childhood adversity (CTQ) and habitual behavior (COHS-C automaticity and routine, respectively) by routines implemented in the PROCESS (Preacher & Hayes, 2004) macro for SPSS. 95% confidence internals (CIs), based on bias-corrected bootstrapping with 5000 permutations, and Sobel test were used to test the significance of indirect effects (Preacher & Hayes, 2008). For all analyses, p values of less than 0.05 were considered statistically significant. Corresponding correlation and mediation analyses were additionally conducted with JASP to further validate the robustness of the results. To control for potential age and gender effects the mediation model was additionally recomputed including these variables as covariates.

3. Results

3.1. Reliability and validity of the COHS-C

The two-factor structure fitted the data (χ^2= 1169.33, df = 323, p < 0.001, χ^2/df = 3.62, RMSEA = 0.068, 90%CI for RMSEA = [0.064, 0.073), SRMR = 0.063, CFI = 0.799, GFI = 0.859, TLI = 0.781, mean factor loading = 0.659, factor loading range = 0.456–0.953), supporting the notion of automaticity and routine being two subscales of COHS-C. Both factors were also moderately correlated with each other (r = 0.575, p < 0.001). Item loadings on both factors were high and significant, indicating high factorial validity of the items. Likewise, reliability of the coefficients for both factors was high as well, i.e. COHS routine (α = 0.841; ω = 0.843) and COHS automaticity (α = 0.844; ω = 0.849), providing further support for satisfactory measurement precision of both subscales.

3.2. Correlations between early life stress, cognitive flexibility, and habitual behavior

Early life stress as measured by the CTQ, was significantly negatively correlated with the control subscale of the CFI ($r = -0.323$, $p < 0.001$) and positively associated with both COHS scales assessing habitual behavior (routine, $r = 0.147$, $p < 0.001$; automaticity; $r = 0.147$, $p < 0.001$). However, there was no significant relationship between early life stress and alternative, as well as alternative and automaticity. Details are provided in Table 1, for correlations with the subscales of the CTQ please see Supplementary Table S2.

Table 1
Correlations between CTQ, CFI, and COHS-C.

	Mean (SD)	CTQ	Alternatives	Control	Routine	Automaticity
CTQ	40.53(13.08)	–				
Alternatives	46.16(8.71)	−0.044	–			
Control	22.86(4.80)	−0.323***	0.234***	–		
Routine	53.47(10.41)	0.147***	0.174***	−0.301***	–	
Automaticity	33.48(9.03)	0.147***	0.039	−0.334***	0.575***	–

*** $p < 0.001$.

Table 2
Indirect effects of mediation models.

Paths	Effect	Boot SE	Boot LLCI	Boot ULCI	z	*p*
CTQ → alternatives → routine	−0.009	0.0124	−0.0364	0.0141	−1.0202	0.3077
CTQ → control → routine	0.0887	0.019	0.0549	0.1295	5.7103	< 0.001
Total	0.0796	0.0251	0.0356	0.1347	–	–
CTQ → alternatives → automaticity	−0.0037	0.0054	−0.0183	0.0046	−0.942	0.3462
CTQ → control → automaticity	0.0779	0.0167	0.0475	0.1139	5.6996	< 0.001
Total	0.0742	0.0184	0.0424	0.1145	–	–

Boot SE: Bootstrap for Standard Error; LLCI: lower-level confidence interval; ULCI: upper-level confidence interval.

3.3. Mediation effects of cognitive flexibility on the association between early life stress and habitual behavior

The mediation model used in this study revealed a significant total indirect effect of cognitive flexibility on the relationship between ELS and routine (Table 2). However, not all aspects of cognitive flexibility showed significant indirect effects. The confidence intervals for the indirect effect of alternatives encompassed zero, suggesting that alternatives was not a significant mediator of the effect of ELS on routine, and results were further confirmed by the Sobel test. Furthermore, there was no significant direct effect in this model (Fig. 2), suggesting a total mediation effect.

Interestingly, we observed a similar pattern for the automaticity facet of habitual behavior, reflected by a total indirect effect of cognitive flexibility on the relationship between ELS and automaticity (Table 2). Only the indirect effect of the control facet of cognitive flexibility was significant, which was further validated by the results from the Sobel test. Moreover, the control facet was a total mediator of the association between ELS and automaticity (Fig. 3).

Summarizing, the level of cognitive flexibility, specifically the control facet, mediated the positive relationship between ELS and habitual behavior (routine and automaticity). Specifically, early life stress had a negative correlation with the level of cognitive flexibility (control facet), which was strongly negatively associated with habitual behavior, for both the routine and automaticity facet (Figs. 2, 3). In additional analyses including sex and age as confounding variables findings from the two mediation models remained stable. To further test the robustness of the mediation we additionally computed a Structural Equation Model (SEM). Results from the SEM confirmed the mediation effect (details see supplements). To further explore sex differences separate correlations and mediation models for male and female participants were computed (see Supplementary Tables S3–6). Results from the sex-specific mediation models confirmed the mediation effects from the main analysis.

4. Discussion

The present study examined the reliability and validity of a Chinese version (COHS-C) of the COHS and to validate the two-factorial structure of habitual behavior assessed by the COHS across different cultures. Generally, the Chinese version of COHS exhibited a good to excellent internal consistency reliability and confirmed the two-factorial

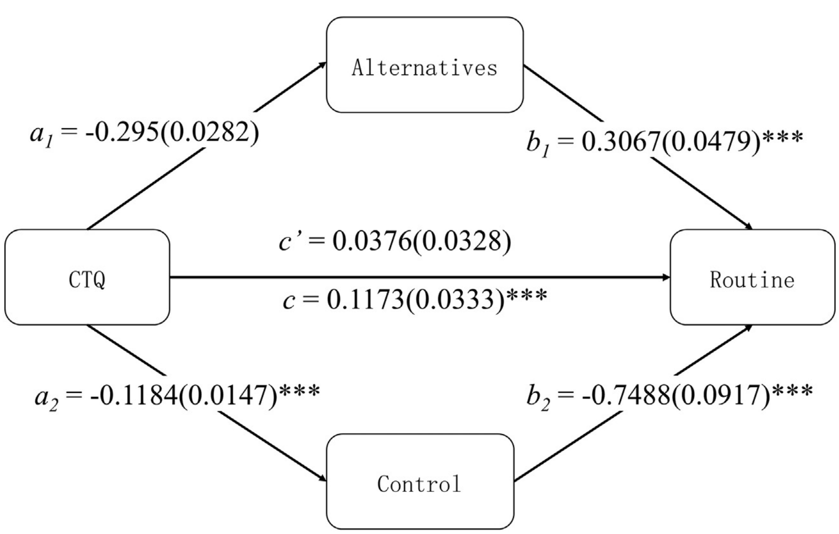

Fig. 2. Mediation model: mediation effect of cognitive flexibility on the relationship between early life stress (CTQ) and routine (COHS). Unstandardized coefficients are presented with standard errors in parentheses. *c′*: direct effect, *c*: total effect, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. CTQ: Childhood Trauma Questionnaire.

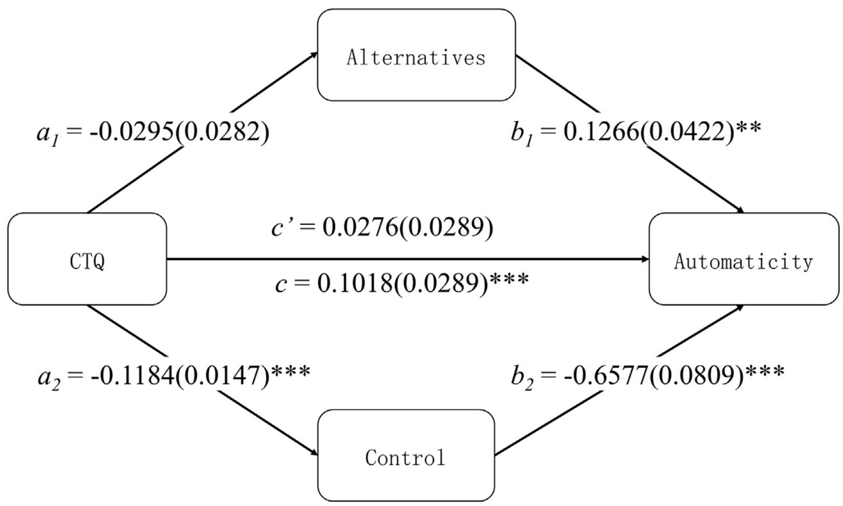

Fig. 3. Mediation model: mediation effects of cognitive flexibility on the relationship between early life stress (CTQ) and automaticity (COHS). Unstandardized coefficients are presented with standard errors in parentheses. *c′*: direct effect, *c*: total effect, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. CTQ: Childhood Trauma Questionnaire.

structure of habitual behavior response patterns in daily life as assessed by self-report. Based on the previous literature, we hypothesized that higher exposure to ELS (before the age of 16) would associate with higher self-reported habitual behavior and lower cognitive flexibility. In the present dataset both hypotheses could be confirmed. Moreover, the major aim of the present study was to explore whether cognitive flexibility would mediate the association between higher ELS and higher levels of habitual behavior. Testing our a priori hypothesis using a mediation model confirmed that cognitive flexibility mediated the association between ELS and habitual tendencies in everyday life. Specifically, higher exposure to adverse experiences during childhood related to more habitual behavior including both, routine and automatic behavioral patterns, in adulthood and the association was totally mediated by impaired cognitive flexibility, especially a decreased ability to perceive self-control over behaviors and environment, but not the ability to perceive and generate multiple solutions. These findings suggest interventions that can improve the control facet of cognitive flexibility, specifically the tendency to perceive difficult situations as controllable, may strengthen the resilience to habitual behavior and may shift disrupted balance towards flexible goal-oriented behavior following elevated levels of adverse early life experiences.

The confirmatory factor analysis demonstrated a moderate model fit, suggesting that the two-factorial solution of habitual behavior reported for the original COHS version (Ersche et al., 2017; Ersche et al., 2019) could be similarly observed in the present Chinese sample. Furthermore, factor loadings of all items were larger than 0.3 indicating that all items contributed to their respective scales, replicating previous results obtained with the original COHS version (Ersche et al., 2019). Both Cronbach's alpha and McDonald's omega for the scales indicate a high internal consistency reliability. Although some model indices suggest a rather moderate fit, similar results for these indices were observed for the original COHS in Caucasian samples (Ersche et al., 2017; Ersche et al., 2019). Together, the findings from the COHS-C suggest that the Chinese version of the original instrument meets the research standards for psychometric scales and its usage in studies in Chinese populations and generally confirms overarching models proposing habit formation in a context-dependent framework (Robbins & Costa, 2017; Wood & Runger, 2016). In the present sample the routine and automaticity subscales exhibited a higher correlation than in the previous assessments (Ersche et al., 2017; Ersche et al., 2019). This subtle difference between the versions may suggest either subtle cultural differences or reflect an effect of aging. The Chinese participants in the present sample were younger than the Caucasian participants in the studies evaluating the original English COHS (Ersche et al., 2017; Ersche et al., 2019) and previous studies suggest that younger adults may undergo a period of stronger stimulus-response learning (Juncos-Rabadan et al., 2008; Mell et al., 2005) to support both routine and automatic behaviors based on context-dependent association.

Our mediation models reveal that higher exposure to childhood adversity was associated with increased habit formation in subsequent daily life. The observed association is in line with accumulating evidence from animal models and experimental studies in humans (Dias-Ferreira et al., 2009; Harms et al., 2018; Park et al., 2017; Schwabe & Wolf, 2011), self-report measurements assessing individual variations in the use of habitual behavior in everyday life (Ersche et al., 2017), as well as accumulating evidence suggesting that current and chronic stress render individuals at an elevated risk for the development of mental disorders characterized by dysregulated habits such as substance dependence (Enoch, 2011; Uhart & Wand, 2009). Habits can reduce cognitive load under stress and ELS-associated behavioral and neural changes have been considered as potential adaptive mechanism to a harmful environment which can become dysfunctional during later adult life and thus promote the development of mental disorders (Teicher et al., 2016; Teicher & Samson, 2016; Uhart & Wand, 2009). From a psychological perspective reliance on automatic or regular responses under stress and in the face of danger may have clear benefits and reduce the load on limited cognitive resources. However, excessive or chronic stress during early sensitive periods has been associated with impaired cognitive functions, including cognitive flexibility which may impede the ability to generate alternative choices and adaptive behavior in the context of changing environmental contexts (e.g. Harms et al., 2018; Stuart et al., 2019). Cognitive flexibility represents an important resource to adaptively cope with stressful life events (Murphy et al., 2012) and ELS-induced impairments in this domain may shift the balance towards automatic habitual behavior. The present findings suggest that cognitive flexibility totally mediates the association between ELS and habitual behaviors. Efficient cognitive flexibility relies on the integrity of the prefrontal cortex, which is thought to implement goal-directed control (Armbruster et al., 2012), particularly model-based learning, which has been demonstrated to protect against habit formation (Gillan et al., 2015). Noteworthy not all aspects of cognitive flexibility totally mediated the association between ELS and habitual behavior, such that specifically the control facet of cognitive flexibility impacted both, routine and automatic habitual behavior. Although the alternatives facet of cognitive flexibility influenced the direct model path associated with habits it did not mediate the association between ELS and habits. Our model thus highlights that the perception of controllability in the face of difficult situations mediates the bias for habitual behavior and may reflect that high levels of stress during early life may lead to a persistent feeling of loss of control over the environment which negatively impacts adaptive flexible behavior in favor of habitual behavior. As Dennis and Vander Wal (2010) proposed a lack of cognitive flexibility could increase a maladaptive tendency to utilize and consider adaptive coping strategies. In line with previous experimental findings (Gillan et al., 2015; Harms et al., 2018; Wood & Runger, 2016) the present self-report findings thus emphasize that ELS-associated deficiencies in cognitive control may aggravate habitual tendencies including both routine and automatic behaviors.

Interestingly, a previous study examining associations between the COHS facets and impulsivity and compulsivity found that routine tendencies have a positive association with compulsivity and negative association with impulsivity, in contrast to automaticity relying more strongly on impulsivity than compulsivity (Ersche et al., 2019). Together with the present findings this may indicate an association between the COHS scales and subclinical symptoms of abnormal compulsive and impulsive behavioral tendencies following elevated ELS which have recently gained increasing interest in disorders of substance use and dependence (Everitt & Robbins, 2016) and obsessive-compulsive disorder (OCD) (Adams et al., 2018; Robbins et al., 2019). In line with these observations accumulating evidence suggests that dysregulated habit learning may represent an important pathological pathway that is central to disorders of compulsivity characterized by a cycle of repetitive maladaptive behavior, including substance dependence (Dickinson et al., 2002; Everitt & Robbins, 2016) and OCD (Gillan & Robbins, 2014; Robbins et al., 2019).

Although the present study focused on healthy participants, it was observed that higher exposure to adverse childhood experiences was associated with stronger implementation of rigid routines and automatic behavioral patterns in everyday life which were mediated by levels of cognitive flexibility. Despite the lack of apparent psychiatric symptoms in the present young healthy sample it is conceivable that stronger reliance on habitual behavior may represent a vulnerability factor for some mental disorders which may become apparent with aging or under re-current/chronic stress exposure during adulthood. Promoting cognitive flexibility may thus represent an opportunity for early intervention and has been demonstrated to be particularly efficient for children and young adolescents, particularly those with low baseline cognitive flexibility and elevated levels of ELS, e.g. due to rearing in institutional care contexts (Crone et al., 2004).

Accumulating evidence from animal models and human experimental research indicates that the dopaminergic reward system and associated fronto-striatal circuits between specific subregions of the striatum and the prefrontal cortex, anterior cingulate cortex and amygdala undergo lasting neuroadaptations as a consequence of ELS (Teicher et al., 2016; Teicher & Samson, 2016). These circuits partly overlap with ones mediating the effects of stress on the development of addiction as well as the effects of stress on the formation of habits (Taylor et al., 2014). Alterations in fronto-striatal circuits following ELS have been suggested to promote diminished anticipation and insensitivity to changes in outcome values as well as task switching and decision making and these functions are crucial for adaptive goal-directed behavior (Teicher et al., 2016; Wood & Runger, 2016). Cognitive flexibility also relies on a network of distributed systems encompassing the prefrontal cortex, anterior cingulate cortex, and striatum (Leber et al., 2008; van Schouwenburg et al., 2012) and dopamine-mediated increases in cognitive flexibility appear to be neurally mediated by effects on fronto-striatal circuits (Stelzel et al., 2013). Stress promotes a more rapid transition to stimulus-response action patterns by inducing a shift to specific striatal circuits, particularly sensorimotor and dorsal striatum loops (Wood & Runger, 2016). Together, these previous neuroimaging and pharmacological studies suggest that ELS-induced adaptations in fronto-striatal circuits may underlie the observed effects which are possibly mediated by deficient engagement of the prefrontal cortex which is important for cognitive flexibility rather than increased engagement of striatal regions that mediate habit formation. Additionally, ELS experience may induce an altered cortisol stress response during childhood, which impairs the prefrontal cortex and may then shift the brain to the striatum habit system. However, associations between individual variations in the COHS subscales and in structural and functional brain systems remain to be determined and these hypotheses require evaluation in future studies.

Notably the two scales of the CFI showed divergent associations with habitual behavior and only individual variations in the control facet, but not the alternatives facet, mediated the association between ELS experience and habitual behavior. Control refers to the tendency to perceive difficult situations as controllable and may have a stronger relationship to the experienced uncontrollability of adverse events during childhood, whereas alternatives may reflect a subsequent coping mechanism stronger related to the ability to generate alternative explanations and potential solutions following adverse experiences during childhood.

The present findings need to be considered in the context of some limitations. For instance, we included the COHS that mainly assesses general habitual tendencies in daily life, but due to the low prevalence of drug use in comparable samples maladaptive habits, e.g. smoking, drug and alcohol abuse were not assessed. Thus, conclusions regarding direct effects of ELS on problematic behaviors remain limited, although the present investigation still allows insights on potential underlying pathways that mediate the detrimental effects of ELS on maladaptive behavioral tendencies. In addition, the study employed self-report measures and early life and chronic stress may lead to defense and protective mechanisms which may affect emotional and self-representational processes outside of the conscious awareness (Becker et al., 2013; Dyakov, 2020; Spengler et al., 2017). Moreover, the present study is a cross-sectional, correlational study based on self-reported measurement and thus findings cannot be interpreted in a causal fashion. We employed a pragmatical estimation of sample size that was based on previous studies. However, post hoc power analysis of the entire model and each path in the model using RMSEA and Monte Carlo based methods respectively (MacCallum et al., 1996; Zhang & Yuan, 2018) revealed an excellent power of the present study with respect to examining the primary hypothesis. Finally, the replicability and generalizability of the present findings should be established in large cohorts from the general population with a broad age range.

5. Conclusions

In the present study we translated and evaluated a Chinese version of the Creature of Habits Scale (COHS) and applied a mediation approach to examine whether the association between exposure to adverse childhood experience and stronger habitual behavior in adulthood is mediated by cognitive flexibility. The Chinese version of the COHS (COHS-C) exhibited good to excellent psychometric properties and confirmed the two-factor structure observed for the original version. In line with our hypothesis cognitive flexibility mediated the association between early life stress and habitual behavior.

CRediT authorship contribution statement

Xinqi Zhou:Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing - original draft.**Yayun Meng**:Investigation, Writing - review & editing.**Helena S. Schmitt**:Formal analysis.**Christian Montag**:Writing - original draft, Writing - review & editing.**Keith M. Kendrick**:Writing - original draft, Writing - review & editing.**Benjamin Becker**:Funding acquisition, Project administration, Validation, Writing - original draft, Writing - review & editing.

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Appendix A. Supplementary data

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