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Executive Functions Predict the Trajectories of Rumination in Middle-Aged and Older Adults: A Latent Growth Curve Analysis

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Previous studies suggest that executive functions (EF)—a set of domain-general cognitive control processes that contribute to the regulation of emotion—are generally associated with ruminative tendencies. However, there is a dearth of research that examines how EF influences changes in rumination over time, especially in middle-aged and older adults who typically experience a decline in EF. To fill this gap in the literature, we analyzed a large-scale combined dataset from the MIDUS Refresher, Daily Diary, and Cognitive Projects. We examined the impact of EF on the trajectory of rumination across 8 days using latent growth curve analysis. We also examined age as a moderator using a latent interaction term in our structural equation model. Higher executive functioning predicted lower levels of baseline rumination and faster rates of decline in rumination over time, which reflect the successful regulation of maladaptive rumination. The age x EF interaction term was not significant, indicating that the impact of EF on the trajectory of rumination was not modulated by age. Our study offers new insights into the cognitive underpinnings of rumination and underscores the beneficial role of EF for effective regulation of ruminative tendencies in middle and late adulthood.

Keywords: rumination, executive functions, older adults, daily diary study, latent growth curve analysis

Executive functions (EF) refer to a set of domain-general cognitive control processes that facilitate adaptive, goal-directed behavior (Hedden & Gabrieli, 2004). EF is deemed essential for successful navigation through many aspects of life, including occupational success, interpersonal relationships, mental and physical health, and day-to-day functioning (Garner, 2009). Notably, EF appears to be subserved by the same brain regions—primarily prefrontal cortex areas—that are responsible for emotion regulation (Ochsner & Gross, 2005; Zelazo & Cunningham, 2007). It is therefore unsurprising that past work with young adults has suggested that deficits in EF generally underlie poor use of emotion regulation strategies, including rumination (De Lissnyder et al., 2012; Demeyer et al., 2012; Pe et al., 2013; Whitmer & Banich, 2007), which is considered to be maladaptive alongside strategies such as avoidance, suppression, and worry (Lyubomirsky et al., 2015).

Rumination can be conceptualized in two ways: as a trait or state. Trait rumination refers to a trait-like, habitual tendency to ruminate in response to negative moods, events, or problems (Nolen-Hoeksema, 1991). On the other hand, state rumination refers to a temporary episode of rumination in response to a stressor, negative mood state, or salient discrepancies between desired goals and one's current state (Watkins, 2008; Watkins & Nolen-Hoeksema, 2014). A state of ruminative self-focus can be temporarily elicited by blocked or hindered attainment of personally relevant goals, and eventually develop into a chronic tendency to ruminate in response to personal challenges (Watkins & Nolen-Hoeksema, 2014; Whiteman & Mangels, 2020). Most studies that examine the relation between EF and rumination have focused on trait rumination, and find the EF deficits generally associated with trait rumination in both clinically depressed and anxious individuals (Harrington & Blankenship, 2002; Olatunji et al., 2013; Ruscio et al., 2015) and nonclinical samples (Pe et al., 2013; Whitmer & Gotlib, 2013). In support of this, two meta-analytic studies found significant negative relations between trait rumination and components of EF that facilitate inhibition of and shifting away from negative thoughts (Valenas & Szentagotai-Tatar, 2017; Yang et al., 2017), although the direction of their relations remains unclear.

However, results from a few studies have highlighted the need to investigate how EF influences not only trait rumination but also state rumination, given their distinctiveness. Specifically, although rumination levels remained relatively stable when assessed over a month, 6 months, and 1 year (Just & Alloy, 1997; Nolen-Hoeksema et al., 1994), they fluctuated considerably when assessed on a day-to-day basis (Lavallee & Campbell, 1995; Michl et al., 2013) and even demonstrated significant changes within a day, with higher state rumination in the morning and evening than mid-afternoon (Moberly & Watkins, 2008). State, but not trait, rumination was also associated with increases in cortisol and negative affect (Hilt et al., 2015). Further, when trait rumination, state rumination, and depressive symptoms were entered into a regression model, only state rumination accounted for a significant portion of variance in sadness and stress recovery (LeMoult et al., 2013). Similarly, state rumination predicted changes in daily ratings of

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negative affect independent of trait rumination (Moberly & Watkins, 2008). Lastly, Zoccola et al. (2010) found that trait and state rumination scores were correlated among females but not males (i.e., males who reported a general tendency to ruminate did not necessarily ruminate in the 2 weeks after a psychosocial stressor was evoked in the laboratory), which suggests that the two may not always be concomitant in nature.

Despite these differences between trait and state rumination, little is known about the relation between EF and state rumination, especially day-to-day changes in the trajectory of state rumination (Joormann & Gotlib, 2010). Recent studies have indicated that the use of emotion regulation strategies in daily life varies considerably within a person, which reflects state selection of strategy use (Hamaker et al., 2017; McMahon & Naragon-Gainey, 2020). Yet only a few studies have attempted to investigate how EF shapes patterns of state rumination over multiple time points, rather than in response to a singular stressor induced in the laboratory. For instance, one prospective study found that baseline deficits in the shifting component of EF predicted greater rumination following stressful experiences 6 weeks after baseline (De Lissnyder et al., 2012); it should be noted that this study focused mainly on the moderating role of EF between stress and rumination. Another prospective study found that EF deficits in the inhibition of negative material predicted the maintenance of rumination over a period of 6 months (Zetsche & Joormann, 2011). However, Connolly et al. (2014) observed that lower levels of EF at baseline failed to predict changes in rumination approximately 15 months later. Considering this, it is important to examine the relation between EF and dynamic patterns of state rumination in daily life (Naragon-Gainey et al., 2017).

In view of the above, we aimed to examine how EF would influence changes in state rumination over time. This is important for two reasons. First, rumination is not a purely static construct but rather one that changes dynamically over time. Second, as stated above, changes in state rumination exert effects on a range of emotional and physiological outcomes above and beyond trait rumination (Hilt et al., 2015; LeMoult et al., 2013; Moberly & Watkins, 2008; Zoccola et al., 2010). Given that EF consists of domain-general cognitive control processes that facilitate adaptive, goal-directed behavior, it is possible that EF may serve to adaptively interrupt the moment-by-moment rumination that arises in daily life.

EF and Rumination in the Context of Aging

Next, we aimed to investigate whether the relation between EF and rumination would be modulated by age. There is a dearth of research on how EF might influence dynamic changes in rumination over time—and especially in middle-aged and older adults, who typically experience cognitive declines in later life. Theoretical accounts generally posit that impairments in EF underlie rumination. Linville (1996) proposes that deficits in the inhibition component of EF lead to the perseveration of negative internal thoughts, despite those thoughts' being irrelevant to the current context. According to the impaired disengagement hypothesis, which alludes to the role of EF deficits in rumination, certain internal or external stressors that conflict with an individual's goals may initially trigger a state of rumination (Koster et al., 2011). Subsequently, if an individual fails to exercise cognitive control (i.e., EF) and disengage attention from those thoughts, a cycle of rumination and negative mood occurs. Those who remain trapped in this cycle for a prolonged period may eventually develop chronic, habitual ruminative tendencies. The H-EX-A-GO-N (Habit development, EXecutive control, Abstract processing, GOal discrepancies, Negative bias) model also suggests that the efficient application of executive control (i.e., EF) is necessary to suppress or discard irrelevant information; EF deficits may therefore cause negative irrelevant thoughts to remain disproportionately accessible in working memory, and/or lower one's ability to override habitual ruminative response tendencies (Watkins & Roberts, 2020). This is expected, given that emotion regulation is well established to be dependent on cognitive control resources, such as EF, which are crucial in facilitating a greater awareness of and ability to regulate emotions (Kryla-Lighthall & Mather, 2009; Morgan & Scheibe, 2014; Ochsner & Gross, 2005).

However, the relation between EF and changes in state rumination over time remains unclear within the context of aging. Prior studies on EF and rumination have centered largely on adolescents or young adults, since older adults are generally assumed to experience fewer or less intense negative emotional experiences in their daily lives (Stone et al., 2010). Since rumination has not been a major focus among middle-aged and older adults, our understanding of the factors that alter rumination in this age group remains limited. Yet the study of rumination in this age group is vital for several reasons. While it is true that ruminative thinking tends to decline with age, such that older participants tend to report less rumination relative to other age groups (Sütterlin et al., 2012), this does not mean that there is an absolute absence of rumination among older adults. Further, the severity of outcomes tends to be worse for older adults who do engage in rumination (Nolen-Hoeksema et al., 1993). For instance, rumination in response to a stressor is more detrimental to the affective and physiological recovery of older adults than younger adults (Robinette & Charles, 2016). Rumination in late life is also associated with accelerated brain aging (Karim et al., 2021), proneness to anxiety, greater arousal predisposition, and poorer health (Ferraro, 2014). Finally, rumination is more likely to occur in the context of medical and cognitive problems, which are typical of those in middle and late adulthood (Nolen-Hoeksema et al., 1993). Since rumination serves as a risk factor for a variety of deleterious psychopathological (e.g., depression, anxiety) and physiological outcomes (e.g., prolonged cardiovascular response) that disproportionately impact older adults relative to younger adults, it is imperative to identify potential protective and intervention factors that can mitigate rumination.

At the same time, it is essential that we take into consideration the role of aging in EF (Phillips & Henry, 2008). Whereas adolescents and young adults display an EF structure with three factors that are clearly interrelated yet separable (i.e., inhibition, shifting, and updating; Miyake et al., 2000; Miyake & Friedman, 2012), children and older adults tend to display an EF structure that is best represented by a single or two factors (Adrover-Roig et al., 2012; Hughes et al., 2010; Hull et al., 2008; Wiebe et al., 2011). This can be attributed to cognitive dedifferentiation, which leads to a decrease in the number of EF factors (Ferguson et al., 2021; Li et al., 2004; Schaie, 1970), and cognitive reorganization, which leads to a decrease in correlations between performance scores on some EF tasks but an increase in others (Zelazo et al., 2004). Apart from changes in factorial structure (Bock et al., 2019), declines in performance on a range of EF tasks have also been documented with advancing age (Bopp & Verhaeghen, 2020; Verhaeghen et al., 2003; Verhaeghen & De Meersman, 1998; Wasylyshyn et al., 2011). Therefore, prior studies that examine EF and rumination in young adults may not be generalizable to or even comparable to middle-aged and older adults, which further justifies our purpose for conducting this study.

Limitations of Previous Studies

Despite the empirical importance of prior studies, they are limited in four major respects. First, most studies are cross-sectional, and thus it is difficult to draw inferences regarding the relation between EF and the course of state rumination. Further, the few prior prospective studies are inadequate in capturing fine-grained changes in state rumination over time, given lengthy follow-up periods—such as 6 weeks (De Lissnyder et al., 2012) and 15 months (Connolly et al., 2014)—that may have obscured some meaningful findings. Hence, we aimed to examine the association between EF and longitudinal changes in state rumination over 8 consecutive days using sophisticated techniques: latent growth curve analysis and structural equation modeling.

Second, research on the link between EF and rumination has centered on adolescents and young adults (Yang et al., 2017), whose development of EF may not be comparable to that of middle-aged and older adults (Bardikoff & Sabbagh, 2017). Yet, previous findings may not be generalizable, as adults in older age groups typically experience substantial cognitive decline in EF and display an EF structure that has been theorized to differ from that of younger age groups (e.g., de Frias et al., 2009). Thus, we focus on middle-aged and older adults. Since there may be potential differences in either EF or ruminative tendencies between middle adulthood and late adulthood, we include age as a moderator in our analyses. However, we were unable to outline any specific predictions due to the scant research on EF or ruminative differences between middle adulthood and late adulthood; most studies simply compare younger adults with older adults (Ferguson et al., 2021; Ricarte et al., 2020).

Third, most prior studies relied on single measures of EF (Yang et al., 2017), which is problematic because of the task impurity problem. That is, performance on a single EF task reflects the putative executive process in addition to the task-specific (idiosyncratic) and systematic variance attributable to the non-EF aspects of the task (Burgess, 1997). For instance, the Stroop task presents participants with a series of words (i.e., "red," "blue," "green," "yellow") that are color-congruent (i.e., the word "red" printed in the color red) or color-incongruent (the word "red" printed in the color green). Since participants are required to inhibit the automatic tendency to respond to the word and instead respond to its color, the Stroop task is typically used as a measure of the inhibition component of EF. However, the task necessarily involves other non-EF processes such as reading speed, lexical access, and color recognition (Sörqvist, 2014), and is therefore not a pure measure of the inhibition component of EF. To address this issue, we used a latent variable approach based on a comprehensive battery of age-appropriate EF tasks (Lachman et al., 2010, Lachman et al., 2014).

We analyzed a large and representative sample of middle-aged and older adults from the Midlife Development in the United States (MIDUS) Refresher study (Ryff et al., 2017). Using latent growth curve and structural equation modeling, we examined the impact of EF on the growth trajectories of state rumination across 8 days, while controlling for a host of covariates that have been shown to influence rumination (Donoghue et al., 2012; Yang et al., 2017). We drew on the impaired disengagement hypothesis and H-EX-A-GO-N model, which allude to the role of EF in rumination, and hypothesized that better EF would predict lower initial levels (i.e., intercept) of rumination and faster declines in rumination over time (slope), and thus reflect the successful regulation of rumination.

Method

Participants

The MIDUS Refresher is a large-scale longitudinal study consisting of five projects that recruited a total of 3,577 American adults from 2011 to 2014 (Ryff et al., 2017). All participants were required to complete the first project—which assessed demographic, behavioral, physical, and mental health factors—before they were eligible to participate in the other projects, which separately administered daily diary, cognitive, biomarker, and neuroscience assessments (Radler, 2014).

After an initial interview and two questionnaires, a battery of EF tasks was verbally administered to 2,763 respondents by phone (Project 3: Cognitive Assessments). A subsample of 782 respondents also completed short interviews about their daily experiences for 8 days (Project 2: Daily Diary Assessments). The EF and daily diary assessments were administered as part of two separate but simultaneously ongoing MIDUS Refresher Projects. Data collection for the MIDUS Refresher studies was approved by the University of Wisconsin-Madison Institutional Review Board, and all participants provided written consent prior to their participation.

Altogether, our sample size ($N = 782$) exceeds that of previous studies (e.g., $N = 37$, De Lissnyder et al., 2012; $N = 200$, Connolly et al., 2014) and is sufficient to achieve adequate power. For a structural equation model with a maximum of four latent variables and 13 manifest variables, a minimum sample size of 342 is required to detect a small effect size of .20 with 80% power at $\alpha = .05$ (Soper, 2018).

Measures

Executive Function (EF)

Five EF tasks from the Brief test of Adult Cognition by Telephone (BTACT) were used because they were found to load onto a factor that represents executive functioning (Lachman et al., 2010). The digit backward span task evaluated working memory: Participants were presented with a series of numbers to recall in reverse order, and performance was indexed by the number of digits recalled up to eight. The category fluency task assessed verbal fluency and processing speed by directing participants to produce as many words as possible for a given category within 60 seconds. Performance was indexed by the number of unique responses generated. The backward counting task measured processing speed by asking participants to count backward from 100 as quickly as possible, and performance was indexed by the number of items correctly reported. The number series task tapped fluid intelligence and reasoning. Participants were given strings of numbers (e.g., 2, 4, 6, 8) and had to deduce the next number (i.e., 10) in the sequence. Performance was indexed by the number of correct answers given. The Stop and Go Switch task (SGST), which tapped inhibition and shifting, involved two single-task blocks and a mixed-task block. The first block comprised congruent trials in which participants were directed to respond "stop" and "go" for the words "red" and "green," respectively. The second block comprised incongruent trials in which participants were directed to respond "stop" and "go" for the words "green" and "red," respectively, and the third block comprised both congruent and incongruent trials. Inhibition was indexed by the difference in reaction time (RT) between congruent and incongruent trials, and shifting by the difference in RT between switch and nonswitch trials. Longer RT reflected poorer performance on the SGST.

Rumination

A six-item measure of rumination was administered daily for 8 consecutive days (Ryff & Almeida, 2018). Participants indicated the extent to which they had experienced each item on a 4-point scale (0 = *all the time*, 4 = *none of the time*) since the time they woke up that morning. For example, "How often did you think about personal problems and concerns?" (see Appendix A). Items specifically sought to assess rumination that is negatively valenced (i.e., unwanted, intrusive, upsetting, and problem-focused) in nature. Participants' scores on all items were subsequently reverse coded such that a higher score reflected greater levels of rumination, then summed to obtain an overall score of rumination for each day.

Results

Descriptive statistics and zero-order correlations are shown in Table 1 (refer to Appendix B for skewness and kurtosis values). All analyses were conducted on Mplus 7.4 with full information maximum likelihood estimation. EF was modeled as a latent variable using confirmatory factor analysis, with the five EF tasks as indicators. The measurement model of EF was evaluated using the following criteria: Root mean square error of approximation (RMSEA) of .08 or .06 and below (indicating acceptable and good fit, respectively); comparative fit index (CFI) close to or greater than .95; and standardized root-mean-square residual (SRMR) of .08 or below (Hooper et al., 2008; Hu & Bentler, 1999).

Thereafter, we fitted latent growth curve models to the rumination data to examine initial levels (intercepts) and changes (slopes) in rumination over time. Since the chi square difference test could not be used to compare the fit of latent growth models, the Akaike information criterion (AIC) and sample-size adjusted Bayes information criterion (BIC) were used to identify the model that best fit the data, with lower values denoting better fitting models (Ram & Grimm, 2009). All reported path coefficients are standardized estimates that are indicative of effect sizes.

Latent Growth Curve Models

Various unadjusted growth models were tested to examine potential changes in rumination across 8 days. First, a linear growth model comprising a latent intercept and linear slope of rumination was assessed by fixing equidistant time scores across the eight time points. The model yielded extremely poor fit and was thus excluded from further analysis (see Table 2). Next, a quadratic growth model comprising a latent intercept, linear slope, and quadratic slope was assessed. The model produced good fit for the data and found a significant quadratic slope mean ($B = .081$, $p < .001$; see Table 2), which suggests significant changes in the rate of rumination over time. The AIC and sample-size adjusted BIC were also minimized on the quadratic growth model, which indicates that it provided the best fit for the data (Ram & Grimm, 2009).

Measurement Models

Given that previous studies have found a unidimensional construct of EF in older adults (de Frias et al., 2009; Ettenhofer et al., 2006; Khoo & Yang, 2020), we tested a one-factor model of EF using confirmatory factor analysis with the five EF tasks serving as indicators. Model fit indices were excellent (see Table 2), and all factor loadings were significant. A two-factor model of EF was also tested, and a chi square difference test showed that the two models did not significantly differ from each other. Therefore, for parsimony, we retained the one-factor model for further analysis.

The full measurement model comprising the one-factor EF and quadratic latent growth curve of rumination also produced good fit (see Table 2). According to Muthén (2012), the latent interaction term does not have a mean, variance, or covariance with other parameters and therefore should not affect the measurement model fit.

Latent Moderated Structural Models

To examine the moderating role of age in the relation between EF and changes in state rumination over time, we ran a latent moderated structural equation model (SEM) and estimated its fit in two steps (Klein & Moosbrugger, 2000). First, we estimated a baseline (null) model in which the quadratic growth factor of rumination was regressed on the latent factor of EF while including all covariates and excluding the age × EF interaction term. Second, we estimated an alternative model that included the additional age × EF interaction term.

To determine which model explained the data better, we used a log-likelihood ratio test since conventional fit indices are not provided for latent moderated SEM. However, we obtained a negative value (Satorra & Bentler, 2010) and were unable to compare the relative fit of the alternate model with that of the baseline model. Following Muthen's (2012) recommendation, therefore, we performed the Wald test to examine whether the coefficients of the rumination quadratic terms would differ for middle-aged versus older adults. The Wald test showed that $W(1) = .59$, $p = .44$, meaning that age did not moderate the relation between EF and changes in rumination. In fact, we found similar results from the alternate model: The age x EF interaction term did not significantly predict any of the growth factors, $\beta_{int} = -.095$, $SE_{int} = .053$, $p_{int} = .072$; linear slope, $\beta_{lin} = -.028$, $SE_{lin} = .078$, $p_{lin} = .718$; or quadratic slope, $\beta_{quad} = -.027$, $SE_{quad} = .084$, $p_{quad} = .753$. Together, our results suggest that the alternate model with the age × EF interaction term did not explain the data better than the baseline model without the interaction term. Therefore, we retained the baseline model with age as a covariate for further analyses.

Results from the unadjusted model (i.e., without covariates) showed that EF significantly predicted initial levels of rumination ($\beta_{int} = -.216$, $SE_{int} = .047$, $p_{int} = .000$); linear slope ($\beta_{lin} = .198$,

Table 1
Descriptive Statistics and Bivariate Zero-Order Correlations

Measures	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Digit backward	5.07	1.53	1																	
2. Category fluency	20.19	6.38	.240**	1																
3. Backward counting	39.07	11.93	.356**	.433**	1															
4. Number series	2.47	1.56	.382**	.367**	.488**	1														
5. Stop and go switch task	1.29	.322	−.135**	−.284**	−.406**	−.225**	1													
6. Day 1 rumination	5.84	3.98	−.139**	−.070	−.104**	−.122**	.088*	1												
7. Day 2 rumination	4.28	3.68	−.065	−.077*	−.084*	−.062	.079*	.629**	1											
8. Day 3 rumination	3.81	3.61	−.081*	−.049	−.057	−.092*	.061	.644**	.658**	1										
9. Day 4 rumination	3.61	3.52	−.077*	−.032	−.064	−.062	.017	.581**	.621**	.700**	1									
10. Day 5 rumination	3.62	3.58	−.047	−.022	−.024	−.030	.007	.536**	.585**	.619**	.702**	1								
11. Day 6 rumination	3.40	3.39	−.027	.003	−.033	−.020	.030	.456**	.503**	.541**	.594**	.700**	1							
12. Day 7 rumination	3.30	3.17	−.089*	−.005	.000	−.021	.050	.483**	.565**	.576**	.631**	.660**	.678**	1						
13. Day 8 rumination	3.29	3.23	−.078*	−.005	−.001	−.053	.022	.531**	.561**	.572**	.620**	.613**	.638**	.693**	1					
14. Age (years)	50.51	14.38	−.141**	−.239**	−.367**	−.200**	.272**	−.105**	−.060	−.072	−.065	−.060	−.047	−.110**	−.117**	1				
15. Sex[a]	1.52	.50	.033	−.025	−.142**	−.143**	.032	.050	.043	.090*	.067	.085*	.046	.012	.074	−.007	1			
16. Race	1.50	1.32	−.019	−.086**	−.086**	−.108**	.036	.033	−.001	−.029	.012	−.042	−.015	−.058	.002	−.106**	.036*	1		
17. Education[b]	7.79	2.49	.222**	.330**	.309**	.394**	−.139**	−.139**	−.096**	−.086*	−.051	−.081*	−.055	−.053	−.079*	−.058**	−.022	−.014	1	
18. Chronic health[c]	2.87	3.12	−.099**	−.127**	−.228**	−.183**	.146**	.300**	.262**	.294**	.248**	.244**	.192**	.207**	.212**	.165**	.123**	.036	−.186**	1

[a] Sex was coded as 1 = Male, 2 = Female. [b] Education was coded on a scale of 1 = No school to 12 = Doctoral or other professional degree. [c] Higher score indicates poorer health.
* $p < .05$. ** $p < .01$.

Table 2
Model Fit Indices and Slope Statistics for Latent Growth Curve Models

	Fit indices							Slope mean		Slope variance	
Models	χ^2	*df*	RMSEA[a]	CFI	SRMR	AIC	BIC[b]	*B*	*SE*	*B*	*SE*
Measurement models											
Executive function (one-factor)	2.80	1	.026	.99	.005	58,323	58,375				
Executive function (two-factor)[b]	3.22	2	.015	1.00	.005	35,855	35,904				
Latent growth curve models											
Rumination											
Linear	334.12***	31	.112	.92	.078	27,477	27,497	−.224***	.018	.099***	.012
Quadratic[c]	143.27***	27	.074	.97	.040	27,295	27,320	*−.846****	*.057*	*.840****	*.135*
								.081***	.017	.011***	.002
Full measurement model	175.16***	65	.025	.98	.030	63,136	63,243				
Structural models											
EF → Rumination (unadjusted)	175.16***	65	.025	.98	.030	63,136	63,243				
EF → Rumination (adjusted)[d]	403.80***	101	.037	.95	.032	53,904	54,042				

Note. [a]RMSEA = root mean square of error approximation; CFI = comparative fit index; SRMR = standardized root-mean-square residual; AIC = Akaike information criterion; BIC = Bayes information criterion; EF = executive function. [b]BIC was adjusted for sample size. [c]Because the quadratic growth model yields two slopes (linear slope and quadratic slope), statistics for the linear slope are shown in italics. [d]The adjusted model includes age, sex, education, and chronic health as covariates.
*** $p < .001$.

$SE_{\text{lin}} = .070$, $p_{\text{lin}} = .004$); and quadratic slope ($\beta_{\text{quad}} = -.147$, $SE_{\text{quad}} = .077$, $p_{\text{quad}} = .055$). When the adjusted baseline model was run with all covariates (age, sex, education, and chronic health), we found results similar to those from the unadjusted model. EF significantly predicted initial levels of rumination ($\beta_{\text{int}} = -.208$, $SE_{\text{int}} = .066$, $p_{\text{int}} = .002$); linear slope ($\beta_{\text{lin}} = .271$, $SE_{\text{lin}} = .100$, $p_{\text{lin}} = .007$); and quadratic slope ($\beta_{\text{quad}} = -.238$, $SE_{\text{quad}} = .109$, $p_{\text{quad}} = .029$). The adjusted model is shown in Figure 1 below. Since the growth model included a quadratic effect, it should be noted that the linear slope represents the rate of change only when time is equal to 0 (i.e., day 1), while the quadratic slope represents how the linear time effect changes for every one-unit change in time (i.e., acceleration or deceleration; King et al., 2018). Thus, higher EF predicted lower initial levels of rumination on day 1 and greater declines in rumination over 8 days.

Discussion

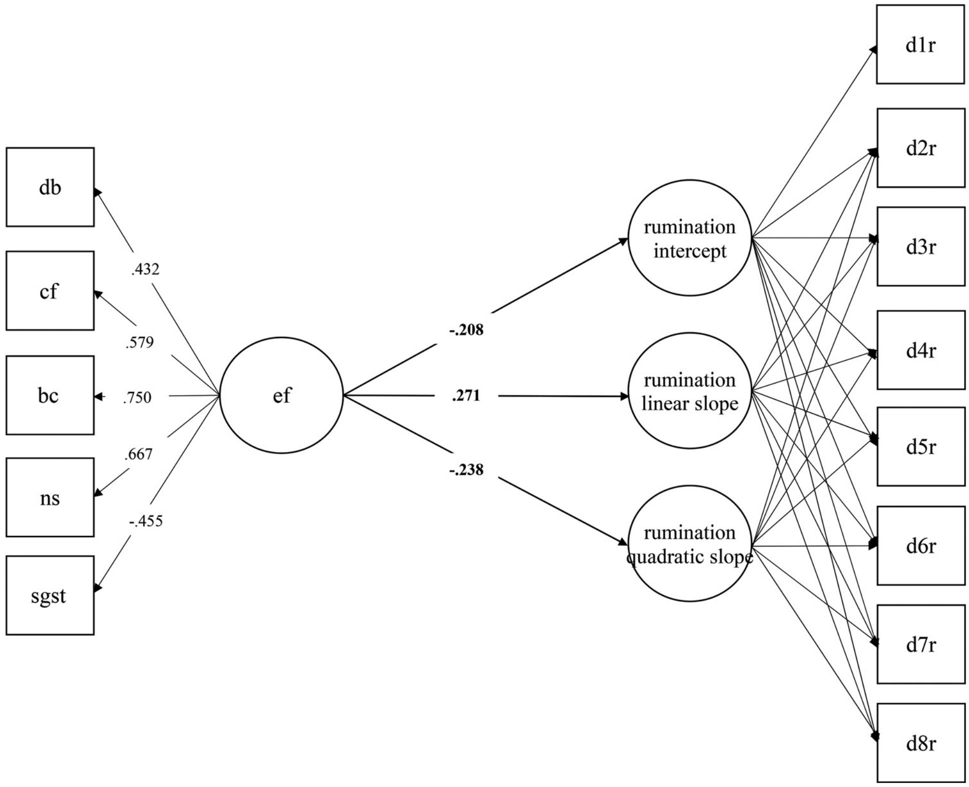
In line with the impaired disengagement hypothesis and H-EX-A-GO-N model, we found that higher EF predicted lower baseline levels of rumination and greater decline in rumination over time, while poorer EF predicted higher baseline levels of rumination and steady patterns of rumination over time. This suggests that EF adaptively facilitates the successful regulation of rumination in middle-aged and older adults, likely through disengagement from or suppression of the ruminative processing of negative information and emotional content (Koster et al., 2011; Watkins & Roberts, 2020). Our finding is corroborated by prospective studies in which individual differences in cognitive control assessed at baseline are shown to predict rumination at a subsequent time (De Lissnyder et al., 2012; Zetsche & Joormann, 2011). Further, our results demonstrate that the relation between EF and rumination was consistent for both middle-aged and older adults and that the two age groups did not significantly differ.

Our study extends previous work in several important ways. First, we leveraged a large-scale dataset that employed a diary study design, which allowed us to take a longitudinal approach to clarifying the relation between EF and the course of state rumination. Our use of latent growth curve modeling also allowed us to observe significant changes in rumination over the eight-day period. This is notable, because previous cross-sectional studies have found negative associations between EF and rumination but were unable to determine the relation between EF and the course of rumination. Our findings advance the literature while demonstrating the importance of investigating the trajectory of rumination when seeking to understand its relation to other psychological constructs (e.g., depression, anxiety, cognitive performance), rather than simply conceptualizing rumination as a time-invariant construct. Another notable contribution of our study is the use of a latent factor of EF based on a comprehensive battery of tasks, which facilitates the partition of true EF variance from non-EF demands and allows for a more accurate estimate of the association of EF with rumination.

Finally, our findings serve to elucidate the role of EF in alleviating state rumination among middle-aged and older adults. This is important, given that rumination has not been a major focus in aging research (Emery et al., 2020), which has more directly examined the broad use of various emotion regulation strategies rather than the specific use of rumination as an emotion regulation strategy. As a result, understanding of the factors that attenuate rumination in this age group remains limited. Our findings shed light on the beneficial role of EF in lessening the use of rumination, which is a maladaptive emotion strategy. Taken together, our study serves as an initial step toward expanding the literature on rumination by demonstrating that differences in EF influence the dynamic aspects of ruminative outcomes, including its baseline and trajectory.

Several limitations should be taken into consideration when interpreting our findings. First, the unidimensional construct of EF may not be applicable to other populations, such as adolescents or young adults who have demonstrated different fractionation of the EF structure (Miyake & Friedman, 2012). Studies suggest that adolescents and young adults display a structure of EF with three factors that are clearly interrelated yet separable (i.e., inhibition, shifting, and updating; Miyake et al., 2000; Miyake & Friedman,

Figure 1
Adjusted Structural Equation Model



Note. db = digit backward span; cf = category fluency task; bc = backward counting task; ns = number series task; sgst = Stop and Go Switch Task; d1r = day 1 rumination; d2r = day 2 rumination, etc. Age, sex, education, and chronic health are included as covariates. Significant paths between executive function (EF), age and rumination factors are indicated in bold ($p < .05$).

2012), while the structure of EF in children and older adults tends to be best represented by a unidimensional or two-factor structure due to age-related dedifferentiation (Adrover-Roig et al., 2012; Hughes et al., 2010; Hull et al., 2008; Wiebe et al., 2011). Because our study lacks a comparison group, we were unable to determine how our findings may differ among young adults. However, given that our primary aim was to investigate the role of EF in shaping the trajectory of state rumination in older adults and that we have accounted for age as a moderator, we believe that our findings still serve to advance the literature on rumination.

Second, recent studies have demonstrated that rumination may be conceptualized as a multifaceted construct, depending on valence, mode of processing (i.e., abstract vs. concrete), and association with different forms of negative affect (Behar et al., 2012; Ciesla et al., 2011). For example, Whitmer and Banich (2007) found that depressive rumination (focusing on thoughts of sadness and loss) was associated with EF deficits in inhibiting previously relevant information, while angry rumination (focusing on thoughts of hostility and revenge) was associated with EF deficits in shifting attention from the current mental set to a new one. Future studies may benefit from investigating how various aspects of EF may influence different facets of rumination.

Third, since the MIDUS Refresher Daily Diary Project was a large-scale study conducted over the telephone rather than in the laboratory, we were unable to control for a singular initial negative event that triggered rumination across all participants. While some studies have focused on specific forms of state rumination, such as following an interpersonal offense (McCullough et al., 2007) or a stressor (Grant & Beck, 2010; LeMoult et al., 2013; Zareian et al., 2021), state rumination has been shown to occur across a range of other contexts of daily life in which its antecedent may not be so readily identifiable. For instance, state rumination may arise in response to a spontaneous thought that focuses on unattained goals (Marchetti et al., 2016). This is corroborated by the control theory account, which hypothesizes that state rumination is initiated by perceived discrepancies between one's goals and one's current reality (e.g., wanting to purchase a car but being in debt) and can occur even in the absence of any immediate environmental triggers (Martin & Tesser, 1996). Given that the measure administered in our study specifically captured participants' ruminative thoughts in response to any personal problems and concerns, upsetting situations, or financial circumstances, the day-to-day changes in rumination in our model should therefore reflect state episodes of rumination initiated by each participants' perceived goal discrepancies in different domains. More importantly, this approach is appropriate for the primary goal of our study, which was to investigate whether higher executive functioning could play a positive role by interrupting state episodes of rumination in middle-aged and older adults, rather than identifying a specific antecedent or factor that contributes to state rumination.

Using a longitudinal approach, our findings offer new insights into the executive processes that predict changes in rumination over time. Within the broader scope of prior literature, our results highlight the need for the temporal dynamics of rumination to be taken into consideration in future studies. Our findings that higher EF keeps initial levels of state rumination low and adaptively facilitates more rapid declines over time have practical implications—specifically, in the development of public health policies and intervention programs that aim to reduce rumination and ultimately enhance mental health in middle-aged and older adults. Accordingly, we expect that training programs that target improvements in EF would help to lower day-to-day engagement in state rumination, which may deteriorate subjective well-being and impede healthy aging while acting as a risk factor for psychopathological outcomes, such as depression and anxiety, in later adulthood.

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(*Appendices follow*)

Appendix A

Daily Rumination/Unconstructive Repetitive Thought Scale (Ryff & Almeida, 2018)

1. How often did you think about personal problems and concerns?
2. How often did you experience thoughts that were difficult to stop?
3. How often did you have trouble concentrating?
4. How often did you have thoughts that kept jumping into your head?
5. How often did you think about situations that upset you?
6. How often did you think about your financial situation?

Appendix B

Descriptive Statistics (Range, Skewness, and Kurtosis)

Measures	Range	Skewness	Kurtosis
1. Digit backward	5.24	.23 (.05)	−.44 (.09)
2. Category fluency	6.74	.29 (.05)	.05 (.09)
3. Backward counting	8.55	.19 (.05)	.47 (.09)
4. Number series	3.20	.02 (.05)	−1.12 (.09)
5. Stop and go switch task	10.12	1.32 (.05)	4.48 (.10)
6. Day 1 rumination	22	1.15 (.09)	1.80 (.18)
7. Day 2 rumination	22	1.70 (.09)	4.18 (.18)
8. Day 3 rumination	24	1.70 (.09)	4.13 (.18)
9. Day 4 rumination	23	1.67 (.09)	3.84 (.18)
10. Day 5 rumination	22	1.67 (.09)	3.60 (.18)
11. Day 6 rumination	22	1.69 (.09)	4.20 (.19)
12. Day 7 rumination	23	1.51 (.09)	3.60 (.19)
13. Day 8 rumination	23	1.72 (.09)	4.69 (.19)
14. Age (years)	53	.01 (.04)	−1.22 (.08)
15. Sex[a]	1	−.08 (.04)	−2.00 (.08)
16. Race	5	2.81 (.04)	6.53 (.08)
17. Education[b]	11	−.12 (.04)	−.95 (.08)
18. Chronic health[c]	27	2.02 (.05)	6.28 (.10)

Note. Standard errors are shown in parentheses.
[a] Sex was coded as 1 = Male, 2 = Female. [b] Education was coded on a scale of 1 = No school to 12 = Doctoral or other professional degree. [c] Higher score indicates poorer health.

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