EXPRESSIVE SUPPRESSION DEPLETES EXECUTIVE FUNCTIONING IN OLDER ADULTHOOD

by

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ABSTRACT

Accurate detection of executive dysfunction in neuropsychological assessments is complicated by the fact that executive functioning (EF) is vulnerable to temporary disruption (i.e., lapses) across the lifespan, with more frequent lapses in older adulthood. Effortful regulation of affect (i.e., expressive suppression) is a well-known source of executive lapses in younger adults, but the generalizability of this depleting effect to older adults is unknown. The purpose of this study was to 1) determine whether EF is subject to depletion via expressive suppression and 2) to explore the possible relationship between depletion and global cognitive status in older adults. We compared the performance of 97 nondemented, community dwelling older adults on a battery of tests measuring EF and component processes both before and after exposure to emotionally-evocative stimuli (in either the nonregulating control group or the expressive suppression group). Participants also completed a screening of global cognitive status at baseline. Consistent with the hypothesized depletion effect, suppressing participants showed an attenuated practice effect on postmanipulation EF relative to controls, while performance on component processes was unaffected by suppression. Level of improvement on executive measures was unrelated to global cognitive status in both groups. These results suggest that depletion contributes to executive lapses in older adulthood.

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INTRODUCTION

Executive functioning (EF) is a broad construct encompassing higher order neurocognitive processes involved in planning, selection, and execution of activity that is purposeful, goal-directed, future-oriented, and socially informed (Suchy, 2016). Accurate identification of executive dysfunction in the course of a neuropsychological evaluation is important for two main reasons. First, deficits in EF are characteristic of a range of clinical populations (for reviews, see Cummings & Miller, 2007; Suchy, 2009); thus, identification of EF deficits has diagnostic implications. Second, EF is arguably the best predictor of independent functioning in daily life (Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002; Chaytor & Schmitter-Edgecomb, 2003; Insel, Morrow, Brewer, & Figueredo, 2006; Kraybill, Thorgusen, & Suchy, 2013). Thus, accurate assessment of EF helps clinicians make recommendations about patients' ability to function independently.

While accurate assessment of EF is important in all clinical situations, it is particularly relevant when assessing older adults. This is because executive weaknesses are present in the early stages of many neurodegenerative conditions that are common in old age, such as frontotemporal and vascular dementias (for reviews, see Engelborghs et al., 2005; Lezak, Howieson, Bigler, & Tranel, 2013). This issue is further compounded by the fact that EF declines somewhat with age, even among high functioning, healthy older adults (Baudouin, Vanneste, & Isingrini, 2004; Hedden & Gabrieli, 2004; Krampe, 2002; Mitsis, 2004). Thus, superimposing even a subtle, preclinical decline in EF due to a neurodegenerative process over normal age-related cognitive changes can lead to an increased risk for functional lapses in daily life (Kraybill & Suchy, 2011; Mitchell & Miller, 2008; Razani et al., 2007; Royall, Palmer, Chiodo, & Polk, 2004, 2005). For example, previous research in our lab has shown that approximately 35% of nondemented, community dwelling older adults (with no more than mild executive weaknesses) make errors on tasks that mimic instrumental activities of daily living, suggesting that they are at risk for functional lapses at home (Suchy, Kraybill, & Franchow, 2011b). Furthermore, subtle EF weaknesses predict decline on a behavioral measure of instrumental activities of daily living over the course of 1 year (Kraybill, Thorgusen, & Suchy, 2013). Thus, the clinical utility of neuropsychological assessments in older patients is clearly dependent in part on accurate estimation of EF. However, the ecological validity of many standardized measures of EF has been challenged (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Burgess et al., 2006).

There are several contributing factors to the limited ecological validity of EF tests. First, standardized executive tests are relatively unreliable from a psychometric standpoint (Ettenhofer, Hambrick, & Abeles, 2006). Second, neuropsychological assessments typically tap into a limited subset of cognitive skills subsumed under EF, and tools needed for comprehensive assessment of all aspects of EF are currently lacking (for a review, see Suchy, 2016). Third, EF tests have traditionally been validated based on the relationship between test performance and the presence of lesions in the neuroanatomical substrates associated with EF (typically, the frontal lobes; Stuss et al., 2002; Stuss, 2011), rather than behavioral outcomes in daily life.

In addition to the typical culprits of poor ecological validity of executive tests, there is an additional, less-commonly considered, contributor to poor ecological validity of EF assessments: the fluctuating nature of EF itself. In particular, there is growing evidence that EF is particularly vulnerable to disruption in the form of temporary "lapses." For example, among both younger and older adults, executive performance fluctuates somewhat in the course of daily life with transient mood states (Martin & Kerns, 2011; Oaksford, Morris, Grainger, & Williams, 1996), poor sleep quality and efficiency (Benitez & Gunstad, 2012; Sutter, Zollig, Allemand, & Martin, 2012), and both acute and chronic pain (Jongsma et al., 2011; Karp et al., 2006; Nes, Roach, & Segerstrom, 2009). Furthermore, older adults show greater intraindividual variability in executive performance compared with their younger counterparts (for a review, see West, 2001; West, Murphy, Armilio, Craik, & Stuss, 2002), suggesting more frequent lapses in later life.

One well-documented source of executive lapses in young adult samples is recent engagement in expressive suppression. Expressive suppression is an emotion regulation strategy involving effortful control of facial affect and other automatic behavioral expressions of emotion, such as laughter or crying (Gross, 1998). Though adaptive when used in moderation (Gross, 2007), expressive suppression is also associated with *increased* amygdalar and autonomic activity (Ohira et al., 2006), making it a highly effortful and physiologically expensive strategy. There is a large body of literature documenting an association between expressive suppression and performance decrements on subsequently administered executive tasks (a "depleting" effect on executive resources), including logic and reasoning, cognitive extrapolation, response inhibition, and working memory tests (for a review, see Baumeister & Alquist, 2009; Inzlicht &

Gutsell, 2007; Schmeichel, 2007; Schmeichel, Vohs, & Baumeister, 2003). Additionally, executive depletion appears more likely in the context of *atypically*-high state suppression (i.e., self-reported levels exceeding the sample mean in the previous 24 hours but lower levels than the sample mean over the previous 2 weeks) (Franchow & Suchy, 2015). However, this research is entirely based on young adult samples.

It is unknown whether expressive suppression continues to deplete EF in older adulthood. There are several reasons to question whether findings with young adults can be generalized to older adults. First, presumably in part because they are more practiced, healthy older adults appear more successful in their emotion regulation efforts than their younger counterparts, with overall reduced negative affect and lower rates of depression (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Charles, Reynolds, & Gatz, 2001). Thus, emotion regulation in general may be less executively demanding for older than for younger adults. The exception to this pattern is older adults who are beginning to exhibit both executive impairments and emotion dysregulation, such as in the early stages of dementia (Lindau et al., 2000; Suchy, 2011; Sultzer, Levin, Mahler, High, & Cummings, 1993). Second, people in their 60s and older tend to report less frequent use of expressive suppression as a regulatory strategy as well as higher rates of proactive coping and positive reframing to avoid emotional upset (John & Gross, 2004; Lang, Staudinger, & Carstensen, 1998). Perhaps due to lower base rates of expressive suppression in later life, there is very limited research documenting the cognitive and behavioral effects of suppression in older samples.

There is also very limited evidence regarding the *specificity* of the depletion effect to EF in younger adults, and the authors are unaware of any published studies addressing this question in older adults. EF encompasses higher order cognitive processes dependent on many lower order component processes (including perception, information processing speed, and basic attention) (Goldberg & Bilder, 1987; Stuss, Picton, & Alexander, 2001; Suchy, 2016). Therefore, it is possible that apparent depletion of EF is actually reflective of a deleterious impact on *underlying* component processes. While the past experimental research has not controlled for component processes when assessing EF, previous research in our lab supports the notion that abnormally high state suppression *differentially* depletes EF (i.e., not affecting processing speed or working memory after accounting for shared variance with EF) (Franchow & Suchy, 2015). This is important from an assessment standpoint considering the diagnostic utility of impairments in related, but dissociable cognitive domains (EF vs. component processes) in older adults (for a review, see Levy & Chelune, 2007; Schoenberg & Duff, 2011).

Purpose of the Current Study

The purposes of the current study were to (a) determine whether EF is differentially depleted by expressive suppression in older adulthood (relative to other related cognitive processes) and (b) explore the relationship between level of depletion and global cognitive status in community-dwelling older adults. To these ends, we administered a battery of cognitive tests to a sample of healthy, community-dwelling older adults, including a global cognitive screening measure as well as tests of EF and component cognitive processes. We then experimentally manipulated expressive suppression in order to induce executive depletion, and retested EF and component cognitive processes.

Based on available evidence in young adult samples, we hypothesized that experimentally manipulated expressive suppression would deplete executive resources, but *not* component processes in older adults. Considering that we would normally expect *improved* performance on repeat cognitive testing (i.e., a practice effect; Lezak et al., 2013), depletion could be indicated either by poorer performance or simply an attenuated practice effect on postmanipulation testing. While there is growing evidence supporting diminished practice effects in the early stages of cognitive decline (Duff et al., 2011; Duff, Chelune, & Dennett, 2012), there is no existing literature examining the association between executive depletion and overall cognitive status. Therefore, our second aim was exploratory and we hope that the present study will serve as a springboard for future research examining the utility of depletion for cognitive assessments in older adults.

METHOD

Participants

Participants were community-dwelling older adults recruited from a local senior health fair and via advertisements distributed to students enrolled in coursework designed for older learners from a local university. Interested individuals provided contact information in person and/or by email and completed screening for study eligibility by phone. Participants were screened for a self-reported history of dementia or mild cognitive impairment. In order to ensure valid interpretation of all cognitive test data, exclusion criteria also included uncorrected vision or hearing impairments, color-blindness, left-handedness (due to evidence of abnormal lateralization of neurological function and potentially different cognitive profiles of left-handed individuals; Gunstad, Spitznagel, Luyster, Cohen, & Paul, 2007; Szaflarski et al., 2002), and motor dysfunction in the right hand/arm (precluding completion of speeded graphomotor tasks; see Measures). In an attempt to control for prior exposure to our measures (i.e., reduce practice effects on baseline testing), individuals who self-reported recent participation in cognitive testing (in other studies or as part of a clinical evaluation) were also excluded.

The total recruited sample who completed all tasks (i.e., with complete data) included 107 older adults. Participants reporting potentially confounding conditions in a more comprehensive medical history questionnaire administered on the testing day were excluded from analyses; this included a history of occipital stroke (N=1), hereditary motor neuropathy (*N*=1), essential tremor (*N*=1), and red/green color blindness (*N*=1). Of this sample, 6 additional participants were eliminated from analyses based on failure to follow instructions to suppress or react naturally per their assigned experimental condition (see Preliminary Analyses). The final sample used in principle analyses included 97 adults who were mostly female (69.1%) and mainly identified as Caucasian (94.8%). Their mean age was 68.74 years (*SD*= 5.54, Range= 60-86) and they had completed the equivalent of a bachelor's degree on average (*M*= 15.98 years of education completed, *SD*= 2.45, Range= 11-21). Through periodic review of group characteristics as the study continued, pseudo-random assignment to either the Suppress (experimental) (*n*=48) or Free Expression (control) condition (*n*=49) was based in part on demographic characteristics in order to ensure similar age, educational achievement, and sex distribution (see Table 1). As can be seen in Table 1, the groups did not differ on demographic variables, recent depressive symptoms (GDS), baseline executive and component process performance, or performance on a global cognitive screening measure (DRS-2).

Procedures

The study was approved by the appropriate university Institutional Review Board and all procedures were in compliance with APA ethical standards. Prior to their arrival for the testing session, participants were pseudo-randomly assigned to either the Suppress (experimental) or Free Expression (control) condition for the executive depletion task. Default group assignment was determined randomly (via an online random order generator), with later participants assigned to ensure group comparability (based on age, sex, and years of education). After undergoing informed consent procedures, participants completed a 3.5- to 4-hour long neuropsychological testing battery one-on-one with an examiner in the Executive Laboratory in the Social and Behavioral Sciences building on the University of Utah campus. Baseline testing included measures designed to assess global cognitive status, EF, and component cognitive processes. Participants then underwent experimental manipulation as part of either the Expressive Suppression or Free Expression condition (see Measures). The same EF and component process measures from baseline testing were then repeated in postmanipulation testing in order to directly measure level of depletion in both domains as a result of engagement in expressive suppression. At the end of the visit, participants were given the option of receiving written and oral feedback regarding their performance on a global cognitive screening measure (either consistent with similar-aged peers, somewhat below expectations, or seriously below expectations) and questions/concerns were answered as appropriate. Participants were encouraged to consult with their primary care physician to obtain referrals for appropriate clinical follow-up and evaluation of any cognitive concerns they may have had, regardless of their performance on this screening.

Measures

Global Cognition

As an estimate of global cognitive status, participants completed the Dementia Rating Scale, 2nd edition (DRS-2) (Jurica, Leitten, & Mattis, 2001) as part of baseline testing. The DRS-2 is an extensively validated screening battery of tasks that assesses cognition in the domains of attention, initiation/perseveration, visuospatial construction, concept formation, and memory in a wide range of patient populations over age 60 (Brown et al., 1999; Kovner et al., 1992; McDaniel & McLaughlin, 2000). A total score across these domains reflects global cognitive ability, with lower scores indicating greater impairment suggestive of a cognitive disorder (Jurica et al., 2001). Previous research in our lab suggests that the total score provides a valid indicator of cognitive status that is also sufficiently sensitive to individual differences in a nonclinical sample (Suchy, Kraybill, & Franchow, 2011a).

Depression

The Geriatric Depression Scale (GDS) is a widely used screening measure for depression in older adults (Yesavage, 1988). The GDS was administered both to characterize the sample and to ensure that any observed group differences in response to the manipulation (including emotionally evocative material) were not the result of baseline differences in recent mood. Participants indicated the applicability of 30 depressive symptoms to their feelings over the course of the previous week in a yes/no format.

Executive Functioning

The Delis Kaplan Executive Function System battery (D-KEFS) is a well-validated, widely used battery of EF (Delis, Kaplan, & Kramer, 2001; Delis, Kramer, Kaplan, & Holdnack, 2004). We included four subtests reflecting widely recognized aspects of EF in both baseline and postmanipulation testing: (1) Trail Making Test, relying heavily on set-shifting and speeded sequencing; (2) Verbal Fluency, tapping verbal initiation and generative fluency; (3) Design Fluency, measuring nonverbal initiation and generative fluency; and (4) Color-Word Interference, reflecting response inhibition and attentional control. As in previous research in our lab (Franchow & Suchy, 2015; Kraybill & Suchy, 2011; Kraybill et al., 2013), scores from these subtests were combined into a single composite score.

Specifically, the following age corrected scaled scores reflecting performance on the most executively dependent conditions from each subtest were combined into the baseline and postmanipulation composites: Trail Making Test: Letter Number Sequencing (Time to Complete), Verbal Fluency: Letter Fluency (Total Correct), Verbal Fluency: Category Switching (Total Correct), Design Fluency: Filled Dots (Total Correct), Design Fluency: Empty Dots (Total Correct), Design Fluency: Switching Conditions (Total Correct), Color-Word Interference: Inhibition (Time to Complete), and Color-Word Interference: Inhibition/Switching (Time to Complete). Importantly, a similar composite score based on DKEFS subtests was found to be sensitive to executive performance differences associated with self-reported recent engagement in expressive suppression in a sample of young adults (Franchow & Suchy, 2015). Both baseline and postmanipulation executive composite scores demonstrated acceptable internal consistency reliability in this sample (Baseline Cronbach's α= .658; Postmanipulation Cronbach's α= .736).

Component Process Composite

In addition to their well-known executive components, the Trail Making and Color-Word Interference subtests of the DKEFS also include conditions designed to measure simpler component processes that contribute to performance but do not rely on EF, such as letter and number sequencing, graphomotor speed, visual attention/scanning, and speeds of color naming and word reading. This allows researchers and clinicians to better account for the effect of these processes on performance of the more complex/executively dependent conditions. Specifically, the Trail Making Test includes conditions measuring speeded visual scanning and cancellation (Condition 1: Visual Scanning), simple line-tracing (Condition 5: Motor Speed), and sequencing *without* switching demands (Condition 2: Number Sequencing and Condition 3: Letter Sequencing). Similarly, the Color-Word Interference Test includes measures of speeded word reading (Condition 1) and color-naming (Condition 2) *without* an interference (i.e., executive) component. Completion times from each of these conditions were combined into baseline and postmanipulation component process composite scores. Both composites demonstrated acceptable internal consistency reliability in this sample (Baseline Cronbach's $\alpha = .672$; Postmanipulation Cronbach's $\alpha = .701$).

Depletion

Based on previously utilized methods (e.g. Muraven, Tice, & Baumeister, 1998; Schmeichel et al., 2003), experimental manipulation of expressive suppression consisted of participants viewing affect-inducing video clips (without audio). Clips were edited into two separate videos with a combined 5-minute viewing time: Video A (2.5 minutes of disgusting content), and Video B (2.5 minutes of amusing content). All clips were gathered from material readily available on the internet, including some clips shown on popular television shows and news. Video A included disgust-inducing images; for example, people with various physical abnormalities and injuries or engaging in activities that viewers often find disgusting (such as eating nonfood items). Disgusting images are commonly used in experimental manipulations of expressive suppression and associated with reliably high autonomic responses as well as subjective unpleasant emotional experience (Gross, 1998). Included in this compilation of disgust-inducing material was one previously validated clip taken from the film Pink Flamingos (Gross & Levenson, 1995).Video B consisted of amusing images, including people and animals in physically comedic situations. Amusing images were included in order to induce positively valenced responses with physiologic similarities to disgust (Hubert, Moller, & de Jong-Meyer, 1993), as shown in similar prior research (Demaree, Schmeichel, Robinson, & Everhart, 2004). Videos A and B were viewed in counterbalanced order across participants and groups in order to control for order effects.

All participants viewed both videos in one of two conditions: (1) Free Expression or (2) Expressive Suppression:

1) *Free Expression*: Participants were instructed to simply view the videos and react naturally (i.e., freely express their reactions via their facial expressions), as if they saw them while watching TV at home. This condition served as a comparison control for the Expressive Suppression condition.
2) *Expressive Suppression*: Participants viewed the videos with instructions to not reveal (via their facial expression or any other observable signals) the reactions they may have had while watching. This condition required that participants engage in expressive suppression, which we hypothesized would include executive depletion.

All participants were observed from behind a one-way mirror (to minimize distraction) and rated on their level of observable reaction to each video on a Likert-type scale (1- No observable reaction to 5 – Constant reactions that were poorly controlled). Participants were also video-recorded while completing this task in order to: a) determine compliance with instructions by independent raters blinded to condition and b) to exclude any participants who appeared not to follow the condition instructions. To ensure that the Expressive Suppression and Free Expression conditions were differentially effortful, a manipulation check was conducted immediately following the task in the form of a Likert-style item querying the level of effort exerted across both videos ("How difficult was the video-viewing task?" 1- Not at all difficult, 2- Somewhat difficult, 3- Fairly difficult, 4- Very difficult, 5- Extremely difficult). To further check compliance with task instructions, participants in both conditions also answered the following question in a free-response format: "What was your approach to completing this [video viewing] task? Please describe how you went about watching the videos in the space below." The DKEFS subtests were then re-administered to participants in both conditions to determine the resulting level of executive and component-process depletion (i.e., the difference between baseline and postmanipulation performances).

Table 1
Participant Demographics and Descriptive Data by Experimental Group

	Free Expression (*N*=49)	Expressive Suppression (*N*=48)	Group Difference (*p*)
Age	68.31 (5.21)	69.19 (5.87)	.436
% Female	65%	73%	.511
Years of Education	15.88 (2.53)	16.09 (2.38)	.666
Depressive Symptoms	4.98 (5.11)	5.46 (5.38)	.654
Executive Baseline	11.87 (1.39)	12.03 (1.49)	.569
Component Process Baseline	12.10 (1.11)	11.85 (1.25)	.298
Global Cognition	138.76 (3.66)	138.92 (3.18)	.817

Note. Depressive Symptoms= GDS total raw score (out of a possible 30); Executive Baseline = Premanipulation composite (DKEFS executive scores); Component Process Baseline= Premanipulation composite (DKEFS speed scores); Global Cognition= DRS-2 total raw score (out of a possible 144).

RESULTS

Preliminary Analyses

Manipulation Check

A postmanipulation questionnaire was administered in order to (1) eliminate any participants who reported regulatory strategies that were directly incompatible with task instructions and (2) to ensure that the two experimental conditions were differentially *effortful* among retained participants (see above). Based on their responses, 3 participants in the Free Expression condition who spontaneously suppressed (against instructions) were eliminated from further analyses. Similarly, 3 participants in the Expressive Suppression condition who reported a confounding lack of regulatory effort of any kind (No strategy) were eliminated from further analyses. As can be seen in Table 2, remaining participants in the experimental condition were significantly more likely to report some form of suppression (i.e., effort focused on regulating their facial expression) while participants in the control condition were significantly more likely to report either no strategy or to indicate that they responded naturally, per task instructions. The incidence of other spontaneous regulatory strategies was also similar across groups (see Table 2). Among retained participants, consistent with differences in observed affect, suppressors rated the video viewing task (across disgusting and amusing films) as significantly more difficult overall. This indicates that the suppression task was at least somewhat effortful, as designed, among participants attempting to regulate their affect.

Participant Reactivity by Experimental Condition, Stimulus Valence, and Order of Presentation

In order to ensure that retained participants were exhibiting reactivity consistent with instructions in the two experimental conditions (to either suppress affective responses or freely express them), independent raters blinded to condition viewed their video-recorded responses to the experimental manipulation and coded each participant's level of reactivity (e.g., detectable facial expression, body language, and/or verbalization) on a Likert-type scale (see above). Due to technical difficulties and/or examiner error during the sessions in question, recordings were unavailable for 4 participants (Free Expression N=1, Expressive Suppression N=3). Consistent with task instructions, recorded participants in the control group exhibited significantly higher reactivity to both the disgusting and amusing films compared with the experimental group (see Table 3). As can be seen in the table, reactivity to the two videos did not differ based on the order of their presentation in either the control or the experimental group. This suggests that the two films evoked comparably strong affective responses within groups. Furthermore, consistent with task instructions, participants in the Expressive Suppression condition were significantly less responsive to both types of stimuli when compared to controls. It can therefore be reasonably assumed that any postmanipulation differences in performance between the two groups were driven by differential exertion of regulatory control.

Zero-Order Correlations Between Cognitive Composites and Demographics

Zero-order correlations among cognitive composite scores (pre- and postmanipulation EF and component processes) and basic demographics (age and education) in the full sample and in the two experimental groups are presented in Table 4. As can be seen, correlations among executive and component process performances were high across groups, as would be expected. As would be expected, age was unrelated to performance in either domain either before or after the experimental manipulation, as age-corrected scaled scores were used when creating composites. However, a distinct pattern between educational attainment and executive performance emerged at the group level: years of education was significantly related to postmanipulation executive performance in the control group only (r=.411, p<.01). This suggests that only those in the Free Expression condition benefited significantly from this form of cognitive reserve to achieve a greater practice effect on executive measures.

Principle Analyses

Expressive Suppression and Absolute Improvement on Executive Functioning and Component Processes Measures

We first examined level of improvement in performance on executive and component process measures to determine whether suppression had a measurably depleting effect on executive practice. Specifically, we conducted a repeated measures analysis of variance with executive functioning and component-process composite scores as dependent variables, test time (pre- vs. postmanipulation) as the within-subjects factor, and experimental condition (free expression vs. suppress) as the between-subjects factor. Results indicated a main effect of time, with significant performance improvement across domain and condition ($F(1, 94)= 204.358$, $p<.001$). An interaction between time and domain was also observed, such that the sample's improvement on executive measures from baseline to retest was greater than their improvement on component process measures ($F(1, 94)= 11.654$, $p<.001$).

As predicted, a significant interaction also emerged between cognitive domain, time, and condition; free expression participants showed a significantly-larger practice effect on executive measures ($F(1, 94)= 12.603$, $p=.001$). Specifically, control participants' average executive score improved by 1.33 scaled score points (nearly 1/2 of a standard deviation) from pre- to postmanipulation testing. Participants in the suppression condition only improved by .8 scaled score points on average. In contrast, participants exhibited a similar improvement in component process scores across conditions; controls' average component-process composite score improved by .65 scaled score points from pre- to postmanipulation testing and participants in the suppression condition improved by .83 scaled score points on average.

Accounting for Expected Practice

Considering that both groups improved from baseline to retest in both domains (i.e., practice effect), we examined whether attenuated executive improvement among suppressors remained significant after taking into account their *expected* retest performance. We used a regression-based method of computing reliable change in order to comprehensively address the influences of baseline test performance and demographic characteristics on participants' retest scores (McSweeny, Naugle, Chelune, & Lüders, 1993). Specifically, we modeled expected retest for the sample in each domain based on observed retest performances in the control group.

In separate linear regression models, postmanipulation executive and component process composite scores were the criterion variables, with corresponding baseline composite scores as predictors. Considering the known associations between demographic factors, cognitive performance, and practice effects (Heaton et al., 2001; Hultsch, MacDonald, Hunter, Levy-Bencheton, & Strauss, 2000; Mitrushina & Satz, 1991), age, sex, and years of education were also included as predictors. We then calculated predicted composite retest scores for the sample based on the resulting regression formulas; the difference between participants' actual postmanipulation performance and these predicted scores represented deviation from expected retest in each domain. A repeated measures analysis of variance model was then conducted with the scores reflecting deviation from expected retest performance used as the dependent variables: domain (EF vs. component-process) was the within-subjects factor and experimental condition (free expression vs. suppress) was the between-subjects factor.

Results indicated a significant main effect of domain, such that the sample's overall component process improvement was actually greater than their executive improvement after accounting for demographic predictors of expected retest performance. This was explained by a significant interaction between cognitive domain and condition ($F(1, 94) = 14.698$, $p < .001$) (see Figure 1). In order to examine simple effects, we conducted separate one-way analyses of variance with deviation from expected retest performance in 1) EF and 2) component processes as dependent variables and experimental condition as the independent variable. Results confirmed that suppressing participants fell significantly short of expected retest performance on executive measures only ($F(1, 94) = 8.176$, $p = .005$). As seen in Figure 2, control participants' average executive score improved by 1.33 scaled score points (nearly 1/2 of a standard deviation) from pre- to postmanipulation testing. In contrast, participants in the experimental condition only improved by .83 scaled score points on average. Participants across conditions deviated from expected retest performance on component process measures to a similar extent ($F(1, 95)= 1.199$, $p=.276$). Figure 3 illustrates the equivalent improvement in component process performance from baseline to retest; control participants' average component-process composite score improved by .65 scaled score points from pre- to postmanipulation testing and participants in the suppression condition improved by .83 scaled score points on average.

Executive Depletion and Global Cognition

To explore possible relationships between global cognitive status and attenuated EF performance improvement (i.e., depletion) among participants in the experimental group, we examined zero-order correlations between global cognition and deviation from predicted retest scores in each group separately. Results are presented in Table 5. Among controls, deviation from predicted retest on executive measures was positively but nonsignificantly related to DRS-2 total raw scores ($r= .259$, $p=.072$), such that participants with better global cognition tended to exceed predicted retest performance. Deviation from expected executive retest performance in the experimental condition was more modestly (and also nonsignificantly) related to global cognitive status ($r= .182$, $p=.220$). This suggests a possible distinction between practice effects and the depletion phenomenon, such that true executive practice (unaffected by regulatory interference) is more closely related to global cognitive status. However, these relationships were nonsignificant in both groups in the current sample.

Table 2
Regulatory Strategies and Task Difficulty by Experimental Group

	Free Expression (N= 49)	Expressive Suppression (N= 48)	Difference
	Strategy Counts		x^2 value
Total Strategies	59	62	--
Suppression	3 (*removed*)	30	--
Natural Responding	7	0	7.39 **
Other Strategy	23	27	.842
No Strategy	26	3 (*removed*)	--
	Participant Counts		x^2 value
At least one strategy	23	48	30.38 **
	Mean Ratings by Group		t value
Task Difficulty	1.63 (.87)	2.04 (1.11)	-2.05 *

Note. Free Expression=control group; Expressive Suppression=experimental group; Strategy counts represent the number of references to the strategy within each condition; Task Difficulty=1- Not at all difficult, 2- Somewhat difficult, 3- Fairly difficult, 4- Very difficult, 5- Extremely difficult; ** p<.01 (two-tailed), *p<.05 (two-tailed).

Table 3
Reactivity Data by Experimental Group and Order of Presentation

Order of Presentation	Free Expression	Expressive Suppression	Difference (*t* value)
Across Order	*N*=47	*N*=45	
Disgusting Film	3.57 (1.21)	1.73 (.85)	8.426 **
Amusing Film	3.44 (1.15)	1.71 (.99)	7.710 **
Disgusting First	*N*=21	*N*=23	
Disgusting Film	3.66 (1.31)	1.56 (.72)	6.630 **
Amusing Film	3.61 (1.11)	1.69 (.97)	6.101 **
t value	.465	-1.395	--
Amusing First	*N*=26	*N*=22	
Disgusting Film	3.50 (1.14)	1.91 (.94)	5.254 **
Amusing Film	3.30 (1.19)	1.72 (1.03)	4.863 **
t value	.915	-.106	--

Note. Free Expression=control group; Expressive Suppression=experimental group; Ratings of reactivity completed by independent raters blinded to condition on the following scale: 1- No observable reaction, 2- Minimal reaction, 3- Occasional reactions, 4- Frequent reactions (with some attempt to control), 5- Constant reactions (poorly controlled); ** p<.01 (two-tailed), *p<.05 (two-tailed).

Table 4

Zero Order Correlations Between Cognitive Composites and Demographics

	Executive Retest	Component Process Baseline	Component Process Retest	Age	Education
Total Sample (*N*= 97)					
Executive Baseline	.825 **	.488 **	.501 **	-.047	.247 *
Executive Retest	--	.580 **	.667 **	-.031	.321 **
Component Process Baseline	--	--	.841 **	-.072	.059
Component Process Retest	--	--	--	-.081	.107
Age	--	--	--	--	.145
Free Expression (*N*= 49)					
Executive Baseline	.852 **	.362 *	.417 **	-.133	.237
Executive Retest	--	.450 **	.595 **	-.038	.411 **
Component Process Baseline	--	--	.841 **	.026	.064
Component Process Retest	--	--	--	-.004	.123
Age	--	--	--	--	.251
Expressive Suppression (*N*= 48)					
Executive Baseline	.829 **	.613 **	.573 **	.017	.255
Executive Retest	--	.670 **	.716 **	-.016	.260
Component Process Baseline	--	--	.846 **	-.136	.065
Component Process Retest	--	--	--	-.133	.098
Age	--	--	--	--	.039

Note. Executive Baseline=Premanipulation DKEFS executive composite; Executive Retest=Postmanipulation DKEFS executive composite; Component Process Baseline=Premanipulation DKEFS speed composite; Component Process Retest=Postmanipulation DKEFS speed composite; ** $p<.01$ (two-tailed), *$p<.05$ (two-tailed).

Table 5

Zero Order Correlations Between Deviation from Predicted Executive Practice, Executive Baseline, and Global Cognitive Status by Group

	Executive Practice Deviation	Executive Baseline	Executive Retest
Free Expression (*N*= 49)			
Global Cognitive Status	.259	.363 *	.502 **
Executive Practice Deviation	--	.000	.476 **
Executive Baseline	--	--	.852 **
Expressive Suppression (*N*= 48)			
Global Cognitive Status	.182	.490 **	.479 **
Executive Practice Deviation	--	.132	.641 **
Executive Baseline	--	--	.829 **

Note. Global Cognitive Status=DRS-2 Total raw score; Executive Practice Deviation=Difference between predicted executive practice and actual executive practice; Executive Baseline=Premanipulation composite (DKEFS executive scores); Executive Retest=Postmanipulation composite (same DKEFS scores); ** $p<.01$ (two-tailed), *$p<.05$ (two-tailed).

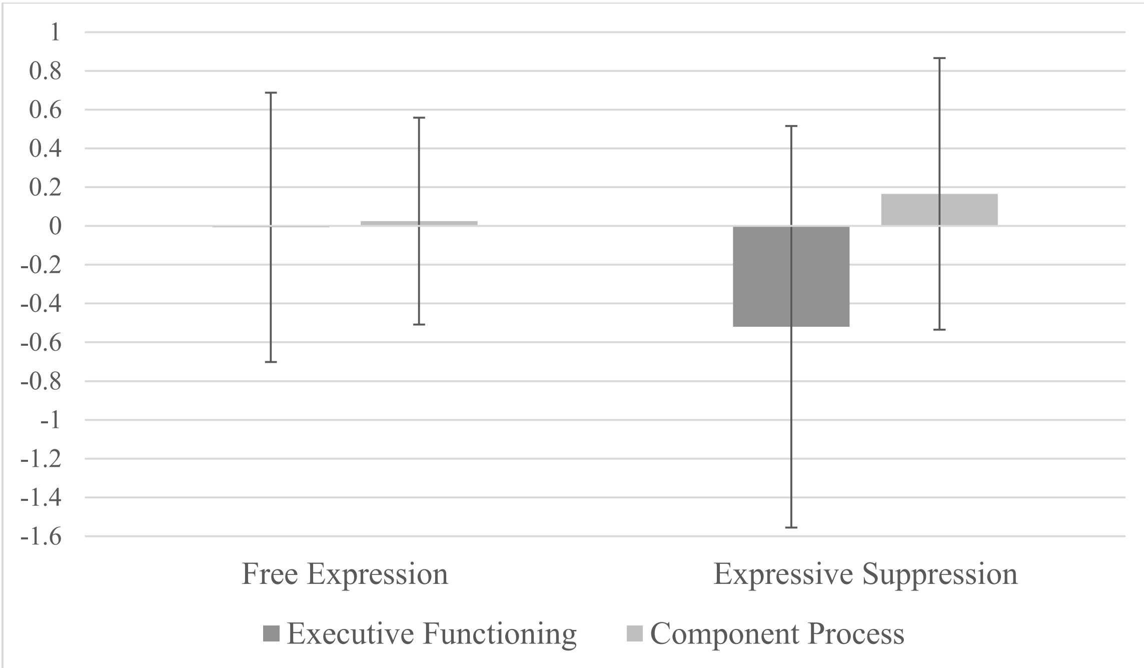

Figure 1. The figure illustrates age-corrected scale score composite deviations from predicted practice effects by domain (executive functioning vs. component process) and condition (free expression vs. expressive suppression). Relative to their predicted practice effect based on controls (i.e., free expression condition), participants in the expressive suppression condition showed an attenuated postmanipulation practice effect on executive measures only.

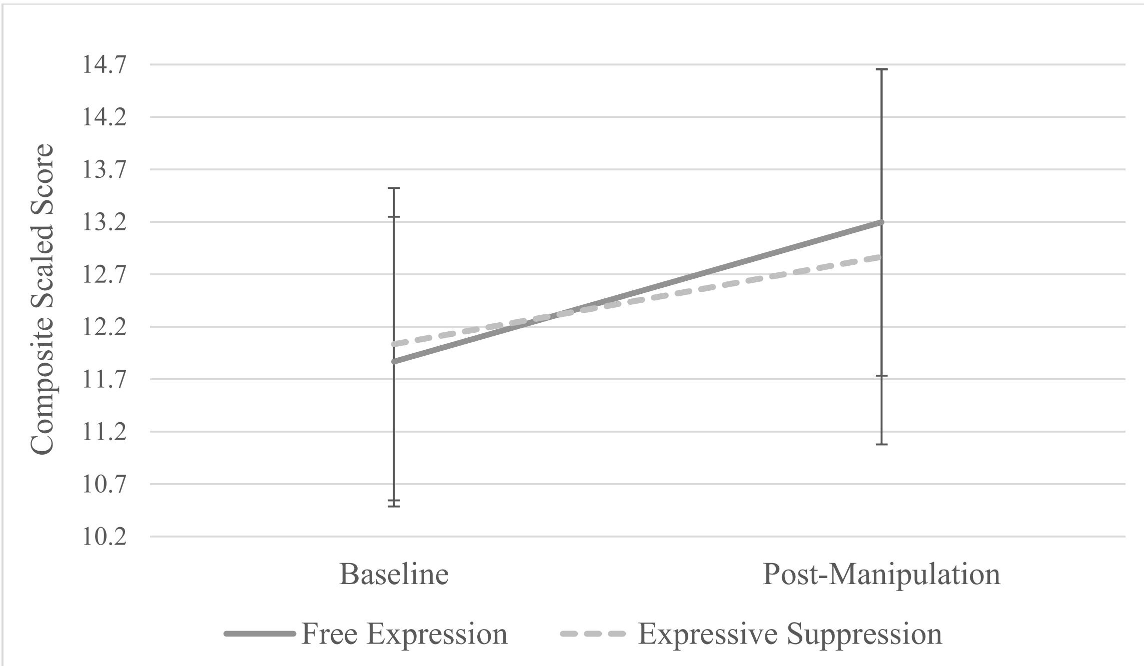

Figure 2. The figure illustrates average executive composite scores by time (baseline vs. postmanipulation) and condition (free expression vs. expressive suppression).

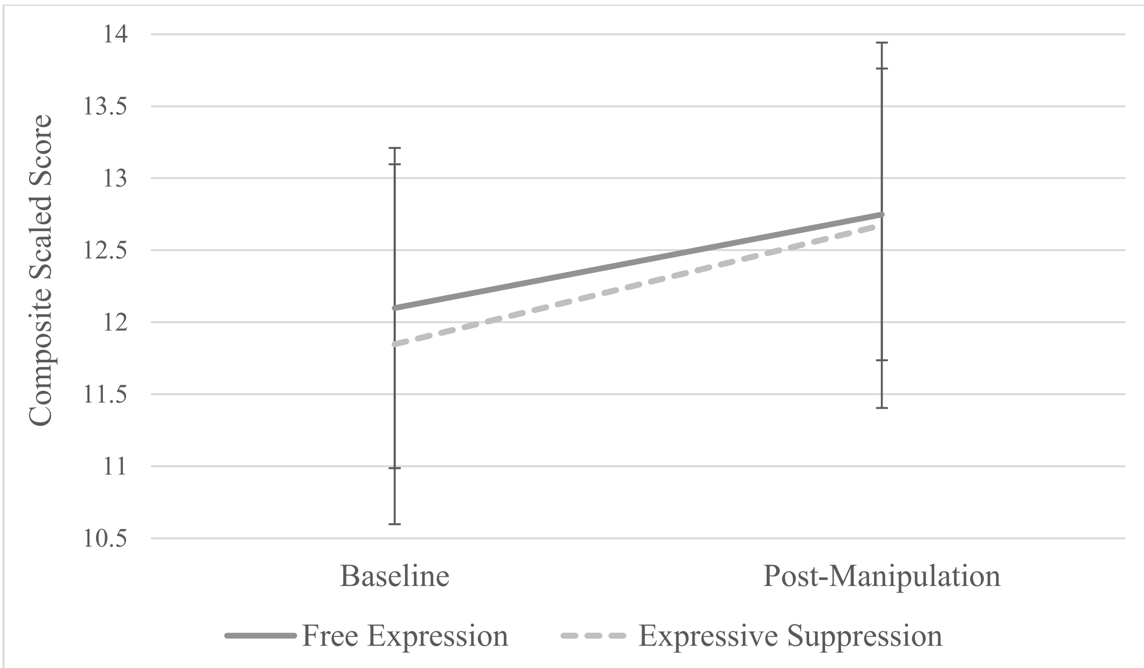

Figure 3. The figure illustrates average component process composite scores by time (baseline vs. postmanipulation) and condition (free expression vs. expressive suppression).

DISCUSSION

The current study was designed to investigate a) whether EF is differentially depleted by expressive suppression in older adulthood (compared with nonexecutive cognitive processes) and b) to explore the relationship between depletion and global cognitive status. To those ends, we recruited a sample of community-dwelling, nondemented older adults and compared their performance on a battery of subtests from the DKEFS measuring EF and component processes both before and after exposure to emotionally evocative stimuli in one of two conditions: free expression (control group) or expressive suppression (experimental group). We also obtained an estimate of global cognitive status at baseline (DRS-2).

The key finding of this study is that EF in cognitively healthy older adults is susceptible to depletion via expressive suppression. Specifically, suppressors showed a significantly attenuated practice effect on postsuppression executive performance relative to a nonregulating control group. This was significant even after accounting for *expected* retest performance in each domain based on demographic predictors. The second key finding is that depletion was specific to EF; in contrast to the significant deviation from predicted executive retest performance observed among suppressors, the two groups exhibited a similar level of improvement on component processes measures. Finally, attenuated executive retest performance (i.e., depletion) was unrelated to global cognitive status, while a trending relationship was observed between a pure practice effect (in the control group) and DRS-2 performance. This suggests that individual differences in the degree of depletion are not related to global cognitive status in healthy elders. To our knowledge, this is the first study to examine executive depletion in older adults. Furthermore, this effect was detectable on standardized tests used in neuropsychological assessments in research and clinical settings.

Implications for Neuropsychological Assessment

These results may have implications for cognitive assessment of older patients and participants. In particular, this experimental demonstration of depletion supports non-psychometric sources of variability on executive tests in older adults; the executive system appears inherently variable in ways that bias performance on a given test day. For example, a person may arrive to a study or clinic appointment after an argument with a family member, navigating stress-inducing traffic, or in the midst of any number of other personal stressors. To the extent that these individuals attempt to hide their emotional upset, as would be socially appropriate, their test performance on a "bad day" might well be an under-estimate of their capacity. By the same token, testing on an unusually good day could over-estimate their capacity under more emotionally evocative conditions in day to day life. Both under- and over-estimation of EF have important implications for the validity and usefulness of their cognitive data. For example, a neuropsychologist might not detect cognitive problems in patients presenting on an especially good day, or consider them to be more functional than they actually are and fail to recommend appropriate safety precautions (such as a driving evaluation or assistance with medications). On the other hand, patients tested on a "bad day" might receive unnecessary diagnoses or restrictions on their independence. Furthermore, if a depletion effect is detectable in a composite score based on four subtests (generally increasing the reliability of results), more erratic variability on single tests may be observed.

Future Directions: Depletion as a Mechanism of Executive Lapses in Older Adults

If executive performance varies as a function of dynamic demands on the regulatory system in older adults, then temporary depletion may in part account for executive lapses in daily life. For example, devotion of regulatory resources to affect control on a bad day might place older adults at elevated risk for functional problems via diminished executive resources. The potentially serious functional consequences of such lapses might include traffic accidents, medication mistakes, financial mismanagement, etc. Thus, capturing the frequency of suppression (or other depleting activities) in older adults might indicate their relative risk for executive lapses and their safety at home. Similarly, older adults who preferentially use suppression to regulate (though they are likely to be the minority; John & Gross, 2004) might be at elevated risk for dysexecutive behavior.

The relevance of depletion as a mechanism of such lapses depends on how the effect operates outside of the laboratory. External validity depends, for example, on the length of depleted states; the more lasting the effect, the greater likelihood that it interferes significantly with older adults' daily functioning. Previous research suggests that a depleted state may persist for some time after the initial regulatory demand, at least within the same 24-hour period (Franchow & Suchy, 2015). However, a more specific estimate in either younger or older adults is unavailable at this time. The functional impact of depletion may also depend on whether certain aspects of EF are more affected than others. EF includes a number of more specific cognitive component processes, including goal-directed information retrieval, working memory, and mental flexibility/shifting (Suchy, 2016). Depletion may affect some of these processes more than others and the specific cognitive processes disrupted may also change over the lifespan. Future research is needed to examine these and other mechanistic questions about executive depletion in older adults.

If in fact executive depletion in older adulthood is cognitively and/or functionally informative, a more practical method of capturing the effect in an assessment context will need to be determined. While an experimental manipulation designed to elicit depletion might capture the phenomenon most directly, researchers and clinicians may easily imagine logistical and ethical constraints on purposefully upsetting vulnerable populations for assessment purposes. Our previous research with younger adults captured depletion relevant for executive performance via self-report; specifically, participants reported the extent to which they had manipulated their emotional expression over the past two weeks as well as the past 24 hours on a Likert-type scale. A brief self-report of recent expressive suppression has the potential to be more practical in an assessment context while minimizing patient discomfort. However, such self-report only provides information about the regulatory burden on any given day, *not* the susceptibility to depletion for any given patient. Future studies should examine the viability of self-reporting expressive suppression in older adult samples.

Depletion: Unrelated to Cognitive Status?

Based on a lack of existing evidence, we made no prediction about the relationship between depletion and global cognitive status. Thus, the lack of relationship in these data is potentially informative regarding the nature of depletion. First, it raises the possibility that depletion indicates a more subtle vulnerability in the executive system that is not captured by a broad cognitive screener; depletion might correspond with pre-clinical executive weaknesses that are predictive of *future* decline, rather than current cognitive status. For example, previous research in our lab suggests that the deleterious impact of novel context on action planning latencies during a motor sequence learning task (termed the "novelty effect") corresponds *not* with baseline cognitive performance, but with the extent of cognitive decline over the course of one year (Suchy et al., 2011a). In other words, one could conceptualize the novelty effect as a sign of diminished functional integrity of the executive system. Similarly, greater depletion effect, at least theoretically, may be an indicator of diminished executive integrity, becoming overtly apparent only over time with further progression of decline. This possibility can only be examined with longitudinal data.

On a related note, the clinical utility of the depletion effect cannot be determined based on a nonclinical sample and the potential impact of depletion in cognitively compromised individuals should be examined in future studies. To the extent that level of depletion is an indicator of the resilience of the neurocognitive systems supporting EF, then declining or dementing adults might be particularly vulnerable to this type of interference. In other words, level of depletion may be diagnostic and/or prognostic. Alternatively, regardless of cognitive trajectory, depletion may be an indicator of functional cognitive integrity under changing circumstances in daily life. On the other hand, depletion may only be detectable in healthy populations with sufficient executive range to show measurable dips in their full capacity (Franchow & Suchy, 2015). Future research with clinical samples will be necessary to examine these possibilities.

Limitations of the Current Study

The current study has several potential limitations. First, though it was our intention to examine depletion in a cognitively and neurologically healthy sample, the applicability of these results to the general population may therefore be limited. The current sample is more highly educated than the general US population (Ewert & Kominski, 2014), and is therefore likely to be unusually high functioning in comparison to the general population of older adults. Most of the sample completed at least some college, and the average educational attainment was the equivalent of a bachelor's degree (16 years). Not only is our sample likely to have higher cognitive reserve than the general population, but many were taking university courses designed for older learners at the time of study participation. In addition to being somewhat more educated than the general public, our sample was particularly homogeneous demographically; the majority of our participants identified as Caucasian and female. It is certainly possible that differences in depletion exist based on ethnic, cultural, socioeconomic, and religious differences not included or measured in this sample. Future studies should examine depletion in larger, more demographically representative samples of older adults.

Second, the conclusions that we can draw about the range of regulatory activity that is potentially depleting in older adults are limited based on these data. Though participants directly violating task instructions were removed from analyses (expressive suppression in the control group and lack of regulatory effort in the experimental group), both groups reported uninstructed and overlapping additional methods of affect regulation. While the current study included a control group (instructed *not* to regulate their affect), we did not include an alternate regulatory condition; for example, a group instructed to positively reappraise or to redirect their attention from upsetting parts of the videos. Training trials in which participants are instructed in a specific strategy and afforded opportunity to practice would also facilitate isolation of "pure" strategies. The purpose of the current study was to examine executive disruption rather than to capture the impact of the full spectrum of emotion regulation per se, and we chose suppression because of its demonstrated detrimental effect on executive performance in younger adults. Additional studies are needed to determine the range of regulatory activities with a negative impact on EF in later life.

Third, the model of depletion suggested by these results may be somewhat limited in its application to everyday life due to the restricted range of emotional responses regulated. Disgusting stimuli are commonly used in experimental manipulations requiring regulation of negative affect, as disgust is associated with reliably high autonomic response as well as consistent subjective unpleasant emotional experience (Gross, 1998). Amusing stimuli were also included to induce positively valenced affect of similar intensity to disgust (Hubert, Moller, & de Jong-Meyer, 1993). However, disgust and amusement clearly represent a small proportion of emotional experience in daily life. To determine whether regulation of less intense negative and positive affect is similarly-depleting in older adulthood, future studies may wish to examine regulation of sadness, irritation, curiosity, joviality, etc.

Fourth, though executive depletion is statistically significant in the current study, the effect size is quite small. The difference of 1.36 executive composite scaled score points gained in the control group versus .8 executive composite scaled score points gained in the experimental group is not enough to amount to a practical or even detectable difference in cognitive assessments. A number of factors that might have contributed to this modest effect have been discussed above, including an unusually well-educated sample and some overlap in regulatory approach between the control and experimental groups. Effect size might also be improved in the absence of within-session practice effects. Future studies may wish to obtain baseline performances on a different day or to match control and experimental groups on level of education or global cognitive status in place of same-session baseline testing.

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