



Does executive function moderate the relation between momentary affective and physical states and subsequent dietary lapse? An EMA investigation

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Abstract The study explored whether baseline individual differences in executive function (EF) affect the relation between elevations in internal states and subsequent likelihood of lapsing from a dietary prescription. Participants were 189 adults with overweight/obesity in a behavioral weight loss treatment who completed a neuropsychological EF task at intake and a 2-week EMA protocol measuring internal states and dietary lapses at start of treatment. Generalized estimating equations found relations between momentary elevations in tiredness ($b = .06$, $p = .01$) and deprivation ($b = .06$, $p = .047$) and subsequent likelihood of lapsing were more robust for participants with lower EF, whereas the relation between momentary elevations in boredom and subsequent likelihood of lapsing ($b = .04$, $p = .03$) was more robust for participants with higher EF. Results provide support for EF impacting the relation between elevations in internal states and likelihood of dietary lapse, informing the development of personalized behavioral weight loss treatments.

Keywords Executive function · Dietary prescription · Adherence · Lapses · Ecological momentary assessment

Introduction

Seven out of ten American adults have overweight/obesity (Centers for Disease Control and Prevention, 2014), but even first-line behavioral weight loss treatments produce less weight loss than is recommended to lower health risks (Wilson et al., 2002). Non-adherence to prescribed negative energy balance diets, i.e., dietary lapse, is a core driver of weight loss failure in these behavioral weight loss programs (Forman et al., 2017; Lowe, 2003). Changes in specific internal factors, such as affective and physical states, have been shown to increase risk of lapse (Carels et al., 2002, 2004; Forman et al., 2017) and these risk factors have typically been measured via ecological momentary assessment (EMA; i.e., a data collection method gathering user feedback in one's natural environment, typically via a smartphone). However, EMA studies examining risk factors of lapse have produced inconsistent findings; for example, hunger has been associated with dietary lapse in some studies (Carels et al., 2001; Forman et al., 2017) but not in others (Carels et al., 2004). It may be that individual differences in certain traits or abilities influence how individuals respond to internal states. For example, some individuals may be at greater risk of lapsing in response to specific triggers (e.g., hunger), whereas others may experience no change in risk, or even reduced risk, of lapse in response to those same triggers. In order to target dietary lapses in a personalized and effective way so to better prevent risk factors from producing lapses, researchers must more comprehensively understand the moderating role of individual differences.

In particular, individual differences in executive function (EF), or a set of cognitive self-regulatory processes including planning, inhibiting impulses, shifting attention, self-monitoring, organizing, initiating activity, and work-

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ing memory, appear to play a key role in dietary and weight-related outcomes, including dietary lapse (Gettens & Gorin, 2017). A large body of evidence implicates EF broadly in the onset, development, and maintenance of obesity (e.g., Crescioni et al., 2011; Groppe & Elsner, 2015; Riggs et al., 2010). Further, studies have demonstrated a moderating role of EF on eating behavior, such that intention to follow a diet was more strongly linked to eating in accordance with that diet among those with higher versus lower EF (Allan, Johnston, & Campbell, 2010, 2011; Hall et al., 2008). Also, EF has predicted dietary behavior (i.e., eating fruits and vegetables) over and above intention to engage in that behavior (Hall et al., 2008). Thus, EF's impact on weight-related outcomes may be due in part to its role in bolstering adherence to dietary prescriptions.

One specific pathway through which high EF may help individuals adhere to a diet is by buffering the impact of affective or physical triggers on dietary lapse. High EF skills (e.g., planning, cognitive flexibility, or inhibitory control) may serve as protective factors against the fluctuations in affective (e.g., loneliness) and/or physical states (e.g., hunger) that can trigger dietary lapse. For example, an individual with high EF may utilize planning skills to map out dietary intake throughout the day to manage hunger. However, an individual with low EF who lacks those planning abilities may experience elevations in hunger that lead her to consume an energy dense food from a vending machine, thereby exceeding her calorie goal. Similarly, an individual with high EF on a diet may experience feelings of deprivation following his decision to replace his daily lunch of two slices of pepperoni pizza with salad. In light of feeling deprived, he may generate ideas as how to appease this feeling, consider alternatives, and adapt his routine by putting meat on his salad, which alleviates his deprivation but keeps him under his calorie goal. This shifting of perspective and approach to facilitate an adaptive behavioral response to a new challenge illustrates the EF skill of cognitive flexibility. Alternatively, an individual with low EF in the same situation may struggle to shift her mindset (employ cognitive flexibility) when experiencing momentary elevations in deprivation and instead default to her habitual response of eating two slices of pepperoni pizza. As another example, an individual with high EF may succeed in inhibiting impulses as they relate to consuming highly palatable food when feeling lonely, whereas someone with low EF may be less likely to inhibit that desire for immediate gratification. Thus, highly developed EF skills may buffer against the fluctuations in affective and physical states that can trigger dietary lapse and impede weight loss.

This study is among the first to explore if baseline EF modifies the relation between momentary levels of affective

and physical states and likelihood of subsequent dietary lapse. We hypothesized that EF would buffer the effect of momentary changes in triggers (i.e., boredom, tiredness, deprivation, sadness, stress, loneliness, irritation, and hunger) on lapse likelihood.

Method

Participants

Participants were 189 adults with overweight/obesity (82.0% female; 70.9% Caucasian; $M_{\text{age}} = 51.8 \pm 9.8$ years; $M_{\text{BMI}} = 36.9 \pm 5.8$ kg/m²) recruited from the Philadelphia area to participate in a randomized trial of two behavioral weight loss treatments (see Forman et al., 2016). This study is a secondary data analysis examining data from baseline and the first 2 weeks of treatment from this larger trial. Informed consent was obtained from all participants included in the study.

Procedures

Participants were randomized to receive one of two behavioral weight loss treatment approaches, consisting of 25 standard behavioral weight loss group sessions across 12 months. Treatment conditions were equivalent for the first 14 days of treatment, allowing for collapsing of data across conditions to evaluate the EMA protocol delivered at beginning of treatment. Drexel University's Institutional Review Board approved all study procedures.

Measures

Executive function

The Achievement Score (the number of moves to complete each trial) on the Delis–Kaplan Executive Function System (D-KEFS) Tower Task (Delis, Kaplan, & Kramer, 2001) served as a behavioral indicator of EF at baseline. The Achievement Score is an overall index of the EF skills needed to complete the task, including planning, cognitive flexibility, and inhibitory control. For this task, participants are given a three-peg base with pre-arranged disks varying in color and size and shown a picture of what the tower's final position should look like. Participants are instructed to build a series of nine towers by rearranging the disks using the least number of moves possible while keeping in mind and adhering to several rules (e.g., a larger disk may never be placed on top of a smaller disk). All administrators of the task were formally trained by an experienced assessor, who served as the criterion rater.

Internal states and lapses

Affective or physical states and lapses were assessed in an EMA protocol during the first 2 weeks of behavioral weight loss treatment. Lapses were operationalized as any eating or drinking likely to cause weight gain and/or put weight loss/maintenance at risk, e.g., eating a larger portion than intended (Forman et al., 2017). Android players (Samsung Galaxy Player 4.0) with custom EMA applications (*Drexel EMA*) were distributed to participants. Written and verbal instructions were distributed to participants on how to use *Drexel EMA* and how to recognize when a dietary lapse had occurred. Specifically, participants were prescribed a daily calorie goal and taught that exceeding this goal constituted a dietary lapse. Participants were prompted to complete six EMA surveys at semi-random intervals each day and to initiate a survey immediately after having lapsed. EMA questions measured negative affect (sadness, irritation, loneliness, and boredom), which were adapted from the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), stress (an internally-developed item based on the PANAS), and physical states (hunger, deprivation, and fatigue), all of which were assessed using a 5-point Likert scale. For example, an EMA question and response type would read: “Right now, how strongly do you feel deprived? (1 = not at all; 2 = slightly; 3 = moderately; 4 = very; 5 = extremely).” Individual PANAS items, rather than a composite, were used because specific affective states (e.g., loneliness) may differentially predict eating behavior (Berg et al., 2014).

Analyses

Individual generalized estimating equations (GEE) models based on a negative binomial distribution with a log link function and a first-order autoregressive covariance structure were used to examine if EF moderated the relation between a lapse risk factor and likelihood of lapse at the subsequent survey. The focus of this study was the interaction between EF (measured at baseline) and within-subject risk factors (i.e., one’s level of a physical/affective state at an EMA survey compared to his/her average level across all EMA surveys). Each GEE controlled for between-subject effects (i.e., differences in individuals’ average level of physical/affective states across all EMA surveys relative to others’) and the reporting of a lapse at the previous survey (which has been shown to predict subsequent lapses in previous studies) (Forman et al., 2017; Goldstein et al., 2018; Manasse et al., 2018). To ensure that compliance was not influencing the results, analyses were repeated controlling for compliance; these results were equivalent and, thus, not reported for the sake of simplicity

and brevity. Between-subject variables were grand mean centered and within-subject variables were centered within person. EF and the interactions between EF and both between- and within-subject internal states were included in each model.

Results

EMA compliance and data characteristics

Average EMA survey compliance was 82.4% ($SD = 13.3\%$). Participants who achieved less than 40% compliance ($n = 3$) were excluded. Following this exclusion, the sample used in the current study was $N = 186$. Across the 186 participants, 13,280 baseline EMA surveys, representing 2604 participant days, were collected.

Interactions between internal states and EF

See Table 1 for within-subject predictors by EF interaction effect statistics. See Fig. 1 for graphs of significant interaction effects. EF moderated the relation between momentary elevations in tiredness and deprivation and subsequent likelihood of lapsing, such that the relations between increased tiredness and deprivation and subsequent lapse likelihood were more robust among participants with lower EF. In contrast and unexpectedly, the relation between momentary elevations in boredom and subsequent likelihood of lapsing was more robust for participants with *higher* EF. EF did not moderate the relations between momentary elevations in sadness, stress, loneliness, irritation, and hunger and subsequent likelihood of lapsing.

Discussion

The results of this study partially support our hypothesis in that EF modestly attenuated the effect of momentary elevations in affective and physical states on lapse likelihood. Individuals with higher EF may use planning, cognitive flexibility, and inhibitory control skills to self-regulate their eating, e.g., through meal prepping, adjusting calorie expectations, and curbing impulses to eat highly palatable food, which may weaken the relationship between momentary elevations in tiredness and deprivation and subsequent dietary lapse. Unexpectedly, those with higher EF demonstrated *increased* likelihood of lapsing in response to boredom.

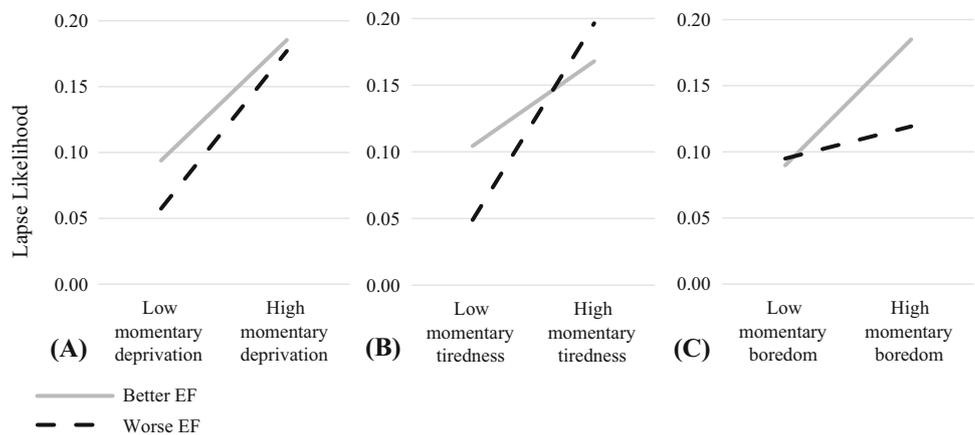
The findings that EF attenuates the impact of both tiredness and deprivation on lapse likelihood are consistent with previous results showing a moderating role of EF on

Table 1 Interactions between EF and momentary (within-subject) physical and affective states on likelihood of subsequent dietary lapse

	<i>b</i>	<i>SE</i>	95% CI	Wald χ^2	<i>p</i>	<i>OR</i>
<i>Physical and affective states × EF interaction effects</i>						
Sadness	− 0.091	.066	[− .220, .039]	1.869	.17	0.91
Loneliness	0.020	.024	[− .027, .066]	0.687	.41	1.02
Boredom	0.042	.020	[.004, .081]	4.621	.03	1.04
Irritation	− 0.002	.025	[− .051, .048]	0.004	.95	1.00
Stress	0.018	.032	[− .045, .081]	0.309	.58	1.01
Hunger	0.003	.035	[− .065, .072]	0.009	.93	1.00
Deprivation	0.057	.028	[.002, .112]	4.067	.04	1.06
Tiredness	0.057	.023	[.012, .103]	6.079	.01	1.06

OR odds ratio. For the purposes of these analyses, EF and physical and affective states were zero centered. In addition, predictors were z-scored to allow for easier interpretation of *b* and *OR* values

Fig. 1 Moderating effect of EF on relation between momentary (within-subject) levels of deprivation (a), tiredness (b), and boredom (c) and likelihood of subsequent dietary lapse



eating behavior (Allan et al., 2010, 2011; Hall et al., 2008). These results raise the possibility that higher EF enables individuals to plan meals and self-monitor hunger in anticipation of tiredness and deprivation, which in turn lowers the risk of dietary lapses. In addition, individuals with strong EF likely have stronger inhibitory control capacity, and thus can inhibit the impulse to eat highly palatable food even when experiencing a triggering state such as deprivation.

The finding that *higher* EF was associated with a slight increase in lapse likelihood in response to boredom contrasted other effects found in the current study and in previous studies (Allan et al., 2010, 2011; Hall et al., 2008). However, the combination of boredom and EF has not previously been examined in relation to risk of lapse. Although those with high EF may be less likely to lapse in response to momentary triggers overall, these individuals do not experience perfect adherence. Thus, some limited set of lapse triggers must still be operative. This study’s results suggest boredom may one such trigger for those with high EF, relative to those with lower EF. It may be that for high EF individuals who are skilled in planning and initiating activity, boredom—or the absence of activity or

stimulation—is a particularly uncomfortable affective state, which may prompt engagement in negatively reinforcing behavior, such as eating.

With replication, this study could inform tailoring of weight loss treatments by providing participants with information about which triggers may make them personally susceptible to lapsing and strategies to target these risk factors to prevent lapses. For participants with poor EF, treatment providers may focus (more than usual) on structured meal planning to limit feelings of deprivation (which trigger lapse) and urge management techniques to curb impulses to eat in response to tiredness. Further, if additional evidence supports that high EF attenuates the relation between internal states and likelihood of lapse, interventions that target and increase EF (e.g., computer-based inhibitory control training) could enhance behavioral weight loss outcomes.

These findings must be interpreted in the context of the study’s limitations. EMA is a self-report measure and subject to human bias, which may have influenced results. In addition, the number of questions in each EMA prompt were limited to reduce participant burden, such that certain affective and physical states that influence dietary lapse

may have been omitted from EMA surveys, precluding investigation into EF's moderating effect on these states' relation with dietary lapse. Another limitation is that interrater reliability was not formally computed among the multiple administrators of the EF task. The study's primarily white and female sample also limits generalizability. Additionally, the increase in lapse likelihood based on the moderating effect of EF was small in each model. Only one dimension of EF was measured, and other EF dimensions may have a more robust relation between risk factors and lapse likelihood; thus, perhaps our methodology precluded us from detecting a larger effect.

Nevertheless, this study provides preliminary support for the idea that EF moderates the relation between elevations in affective and physical states and likelihood of subsequent dietary lapse. Future work should aim to replicate these results in more diverse samples and longitudinally. In addition, future research may examine if assessing EF momentarily (e.g., brief inhibitory control task) and concurrently with measurement of internal states changes the current findings. Continued investigation into the influence of individual differences on dietary lapse and weight loss efforts may allow for more personalized, tailored interventions that can improve behavioral weight loss treatment outcomes.

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Compliance with ethical standards

Conflict of interest Evan M. Forman reports royalties from Oxford Press for two workbooks on acceptance-based treatment. Rebecca J. Crochiere, Clare Jocelyn Mangubat, and Stephanie M. Manasse declare that they have no conflict of interest.

Human and animal rights and Informed consent All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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