INTRODUCTION

Self-control refers to the voluntary processes by which people regulate their behavior, thoughts, and emotions in such a way that the pursuit of long-term goals is promoted over the satisfaction of immediate desires. Given the crucial role of these processes in goal-directed behavior, it is not surprising that the personal ability to exert self-control successfully and consistently (trait self-control) predicts a multitude of important life outcomes in the domains of mental, physical, social, and economic well-being (de Ridder et al., 2012; Moffitt et al., 2011; Tangney, Baumeister, & Boone, 2004). Self-control comprises both preventive (i.e., avoiding or constraining situations that might trigger conflict-laden desires) and reactive strategies (i.e., inhibiting the pursuit of immediate desires when they collide with long-term goals). The former strategies often require the use of executive functioning, which encompasses a variety of cognitive processes that enable goal-directed behavior, such as attentional control, working memory, and decision-making (Miller & Cohen, 2001). This study examines how chronic stress affects the use of cognitive control for self-control in real-life situations.
and reactive components (Hofmann & Kotabe, 2012). Reactive self-control, which is in the focus of the present work, is thought to be activated when a desire-goal conflict is detected, with stronger conflicts activating stronger control motivation (Kotabe & Hofmann, 2015). Successful reactive self-control can be achieved by relatively effortless “early” strategies that require timely conflict detection (de Ridder, Kroese, & Gillebaart, 2018), and a growing body of evidence suggests that such early strategies are especially important for long-term goal pursuit and well-being (e.g., Milyavskaya & Inzlicht, 2017; Nielsen et al., 2019). Early reactive self-control involves several forms of emotion regulation that serve to keep emerging desires from growing irresistible (Hofmann, Kotabe, Vohs, & Baumeister, 2015; Nielsen et al., 2019): Attentional deployment by distraction (turning attention away) or concentration (focusing on a specific task) can interfere with the emergence of desire by occupying working memory, thereby impeding further elaboration of desire-related intrusions (May, Kavanagh, & Andrade, 2015). Later on, but still early in the self-control process, emotion-regulation strategies such as reappraisal (interpreting desire-related stimuli in a way that changes their emotional impact; Kelley, Glazer, Pornpattananangkul, & Nusslock, 2019) or acceptance (relating to desire-related experiences as transient events observed from a distanced and nonjudgmental perspective; Tapper, 2018) can be used to downregulate the strength of desires. When a prepotent tendency for desire enactment, proportional in magnitude to desire strength, is eventually activated, early desire regulation strategies can be complemented by “late” resistance strategies such as inhibiting or overriding desire enactment (i.e., suppressing enactment or performing an incompatible behavior) (Hofmann, Schmeichel, & Baddeley, 2012). Apart from varying between individuals, the ability to exert self-control successfully also varies across situations (state self-control) (de Ridder et al., 2018). Using smartphone-based experience sampling of everyday temptations, Hofmann, Baumeister, Förster, and Vohs (2012) found evidence that personality has a stronger impact on early components of the reactive self-control process (desire strength and the experience of conflict), whereas later components (resistance and desire enactment) are more strongly influenced by situational factors.

Like self-control, chronic stress is also broadly—albeit negatively—related to various domains of well-being (Cohen, Janicki-Deverts, & Miller, 2007; Marin et al., 2011; Thoits, 2010). Acute stress comprises physiological, psychological, and behavioral responses to demands that exceed an organism’s regulatory capacity, especially in uncontrollable or unpredictable situations (Koolhaas et al., 2011), and is generally considered adaptive. However, when stressful situations are ongoing or regularly repeated over prolonged periods of time, thereby inducing chronic stress, protracted activation of the stress response system becomes maladaptive, and may eventually cause a host of physiological dysregulations as well as disruptions in brain structure and function (Ellis & Del Giudice, 2014). Considering the large inter-individual variability in stress exposure and sensitivity (Kudielka, Hellhammer, & Wüst, 2009; Riboni & Belzung, 2017; Schetter & Dolbier, 2011), it can be assumed that people encounter their daily desire-goal conflicts under varying degrees of stress. Both acute and chronic stress are associated with alterations in neurocognitive processes involved in self-controlled decision making (Girotti et al., 2018; Herrmans, Henckens, Joëls, & Fernández, 2014; Starck & Brand, 2012, 2016): First, stress affects the reward system in such a way that the value of immediate rewards is increased, thus increasing the strength of immediate desires. Second, and of particular relevance for self-control, stress can reduce the use of cognitive control, that is, the general executive ability to maintain goal representations in working memory and use them for modulating ongoing cognitive processes to align behavior with superordinate goals (Miller & Cohen, 2001). Corresponding stress-related shifts from goal-directed to habitual or impulsive responding have been observed under laboratory conditions (e.g., Maier et al., 2015; Rahdar & Galván, 2014; for a review see Schwabe, 2017), and there is converging evidence that real-life self-control is impaired under chronic stress (e.g., Chao, Grilo, White, & Sinha, 2015; Duckworth, Kim, & Tsukayama, 2013; Nielsen, Bauer, & Hofmann, 2020; Wang, Wang, Gaskin, & Wang, 2015). However, previous studies have not investigated whether stress-related impairments of real-life self-control are actually due to a reduced use of cognitive control under chronic stress, although this could be an important mechanism underlying self-control failures and related mental disorders (Goschke, 2014).

The present study aims to address this research need using an individual differences approach. Inter-individual variability in different executive functions (EFs) such as inhibition, shifting, and updating depends in part on function-specific abilities, but rests to a substantial degree on a common factor referred to as general executive functioning (GEF; Friedman & Miyake, 2017). GEF is assumed to reflect individual differences in the ability to use goal representations maintained in working memory for modulating ongoing cognitive processes, that is, the assumed core mechanism of cognitive control (Miller & Cohen, 2001; Miyake & Friedman, 2012). Cognitive control is required for early and late reactive self-control strategies (Hofmann, Schmeichel, et al., 2012; Hofmann & Vohs, 2016). From this it follows that individual differences in GEF should affect self-control in terms of both desire regulation and resistance. However, since the use of cognitive control can be impaired under stress, stronger GEF should be reflected in more successful self-control only among relatively non-stressed individuals. Hence, we hypothesized that higher degrees of chronic stress are associated with a weaker impact of GEF on real-life self-control
in terms of the efficacy of early desire regulation (hypothesis 1) and late resistance strategies (hypothesis 2). These hypotheses were operationalized as moderating influences of chronic stress on associations between GEF and (1) the perceived strength of conflict-laden desires and (2) the enactment of conflict-laden desires in cases of attempted resistance during experience sampling of real-life self-control conflicts.

2 | METHODS

2.1 | Participants

After obtaining approval from the institutional review board, 338 young adults (age 19–27; 199 female) were recruited from a representative community sample from the city of Dresden, Germany, for a longitudinal investigation on daily self-control failures and the onset and course of substance-related and addictive disorders. These disorders are not in the focus of the present investigation, but see Appendix A for a summary of related diagnostic criteria in the study sample. Based on a structured interview, participants were excluded if they had neurological conditions that might affect cognition or motor performance, lifetime schizophrenia or psychotic symptoms, bipolar disorder, somatoform-, anxiety-, obsessive-compulsive or eating disorders, or major depression in the last 4 weeks.

2.2 | Materials, design, and procedure

Participants completed assessments of chronic stress levels, real-life self-control, and executive functioning on separate visits to the research facility. All but six participants completed the assessments in that order. The median interval between assessments of chronic stress and real-life self-control was 29 days. The median interval between assessments of real-life self-control and executive functioning was 11 days.

2.2.1 | Assessment of chronic stress

Chronic stress was measured using the screening scale of the Trier Inventory of Chronic Stress (TICS; Schulz & Schlotz, 1999), a standardized questionnaire for the assessment of nine interrelated factors of self-perceived chronic stress with excellent reliability (Petrowski, Paul, Albani, & Brähler, 2012). TICS items refer to stress-related experiences whose frequency in the last three months is rated on a scale from 0 (never) to 4 (very often). The screening scale (TICS-SSCS) comprises 12 items covering five aspects of chronic stress: chronic worrying (e.g., “Times when I cannot suppress my anxious thoughts”), lack of social recognition (e.g., “Although I do my best, my work is not appreciated”), excessive demands at work (e.g., “Times when I perform worse than is expected from me”), work overload (e.g., “When I have too many duties to fulfill”), and social overload (“The experience that all the things I have to do are just too much for me”). High TICS-SSCS scores indicate high levels of chronic stress.

2.2.2 | Assessment of real-life self-control

Everyday self-control was assessed using an experience sampling protocol adapted from Hofmann, Baumeister, Förster,
and Vohs (2012). Participants were provided smartphones equipped for experience sampling (using the customizable application movisens XS), which they carried with them continuously for 7 days. Eight alarms per day were issued randomly within a 14-hour time window starting at either 8, 9, or 10 a.m., depending on participants’ habitual waking hours. Upon accepting an alarm, participants were prompted to complete a short questionnaire on the device to examine the occurrence of self-control episodes in the hour preceding the alarm. The questionnaire, which comprised up to seven items regarding desire, domain of desire, desire strength, conflict, conflict strength, resistance, and enactment, is summarized in Table 1. Depending on response rates, each participant completed up to 56 questionnaires.

### 2.2.3 Assessment of executive functioning

Individual differences in executive functioning were assessed following the latent-variable approach introduced by Miyake et al. (2000), using a battery of nine EF tasks. Table 2 provides a description of each task. Since participants may balance speed-accuracy tradeoffs differently (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010), it was impossible to appropriately quantify performance using error rate (ER) or response time (RT) alone for most tasks. Therefore, where appropriate, we combined ERs and RTs into inverse efficiency scores (IESs; Bruyer & Brysbaert, 2011) by dividing the mean RT of correct responses by the proportion of correct responses (RT/ [1 – ER]). IESs were not used for the stop signal task, where ERs were held approximately constant across participants by an adaptive tracking algorithm, and the letter memory task, where speeded responses were not required. For those tasks whose outcome measures did involve IESs, ERs were calculated using wrong-key errors. RTs for error trials were eliminated. RTs for trials immediately following wrong-key errors and RTs below 100 ms were also eliminated. To obtain the best measure of central tendency, RTs deviating from the median by more than 3.32 median absolute deviations were excluded (Wilcox & Keselman, 2003). For the adaptive stop signal task, which was analyzed according to the quantile method proposed by Congdon et al. (2012), no within-subject procedures were applied apart from eliminating RTs for error trials. For the letter memory task, whose outcome did not involve RTs, ERs were arcsine transformed to improve normality. Table 3 provides information on exclusion of observations, between-subjects trimming, and reliabilities.

### 2.3 Data analysis

Data analysis was performed in the following steps: First, experience sampling data were entered in a path model of self-control describing the relationship between desire and conflict strength, resistance, and enactment. Second, outcome measures were calculated for each EF task, and a measurement model was fitted to these observations and validated using confirmatory factor analysis. Eventually, structural equation models (SEMs) based on the measurement model and experience sampling data were used to test our hypotheses regarding the role of chronic stress as a moderator of the relationship between GEF and real-life self-control. All models were estimated with Mplus 7.4 using the estimator MLR.

#### 2.3.1 Path model of self-control

To address the nested data structure—situations (Level 1) nested within participants (Level 2)—experience sampling data were analyzed using a two-level path model with random intercepts. To restrict the analysis to self-control situations, only those situations where conflict was reported were included in the model, yielding an average of 11.15 Level-1 data points per participant. The model, which was based on the core model of self-control described by Hofmann et al. (2012), was constructed by regressing enactment on resistance, desire strength, conflict strength, and interactions of resistance with desire strength and conflict strength. Resistance was regressed on desire strength and conflict strength. The continuous independent variables desire strength and conflict strength were person-mean centered to remove between-person variance and estimate the unbiased strength of relationships at Level 1 (Enders & Tofighi, 2007). Logistic regression was applied since the dependent variables enactment and resistance were dichotomous.

#### 2.3.2 Measurement model of executive functioning

Before entering them in models, EF task outcomes were standardized and reversed so that higher scores indicated better performance. The measurement model, which was compared against alternative models (see Table 4) and selected applying Karr et al.’s (2018) lenient criteria for model acceptance (CFI ≥ .90; RMSEA ≤ .08) and model selection (ΔCFI ≥ .005; ΔRMSEA ≤ −.010), included the three correlated first-order latent factors Inhibition, Shifting, and Updating, each representing abilities in one EF as indicated by three respective EF task outcomes. This model was extended by the second-order factor GEF, which represents the variance shared by the three first-order factors, and served as the basis for subsequent SEMs. Since the scale of GEF was determined by fixing its variance of at 1, this factor can be treated as a standardized variable.
| Task                  | Description                                                                                                                                                                                                                                                                                                                                                     | Outcome measure                           |
|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| **Inhibition**       | **Go-nogo** On each trial a fixation cross (750 ms) was followed by two vertically or horizontally arranged dots (500 ms). Participants were instructed to press the response key on “go” trials (dots vertically arranged), but to withhold the response on “no-go” trials (dots horizontally arranged). There were 280 “go” and 40 “no-go” trials.                                                                 | IES (using “go” RT and “no-go” ER)        |
|                      | **Stop signal** On each trial a fixation cross (750 ms) was followed by a left- or right-pointing arrow. There were 200 “go” and 40 “stop” trials. On “go” trials, the arrow was shown for 1,000 ms and participants were instructed to press the response key corresponding to the direction of the arrow. On “stop” trials, the sideward-pointing arrow was replaced by an upward-pointing arrow after a variable stop-signal delay (SSD), and participants had to withhold the response. To achieve a stop-trial ER of approximately 50% for all participants, the SSD (initially 200 ms) was adapted after each “stop” trial by adding 50 ms for a (correct) non-response and subtracting 50 ms otherwise. | Stop-signal reaction time (SSRT), estimated according to the quantile method (Congdon et al., 2012) |
| **Stroop**           | On each trial a fixation cross (750 ms) was followed by a stimulus (1,000 ms) consisting of a row of one, two, three, or four identical digits from 1 to 4. Number and denotation of digits were either congruent (80 trials) or incongruent (80 trials). Participants were instructed to respond according to the number of presented digits by pressing the leftmost key for one, the second-leftmost key for two, the second-rightmost key for three, and the rightmost key for four digits. | IES difference between “congruent” and “incongruent” trials |
|                      | **Shifting** Throughout the task the screen was divided into four quadrants by a horizontal and a vertical line. On each trial a digit-letter pair (e.g., 2a or g9) was shown for 3,000 ms in one quadrant. Digits were either even or odd, and letters were either vowels or consonants. Participants were instructed to use two response keys to indicate whether the digit was even or odd (when the stimulus was shown above the horizontal line), or to indicate whether the letter was a vowel or a consonant (when the stimulus was below the line). “Switch” trials alternated with “no-switch” trials as the stimulus location was rotated in a clock-wise direction from trial to trial. There were 128 trials in total. | IES difference between “switch” and “no-switch” trials |
|                      | **Color-shape** On each trial a fixation cross (600 ms) was followed by a cue word (either color or shape; 200 ms), a blank-screen cue-stimulus interval (CSI; 200 ms), and a stimulus (1,500 ms). The stimulus had the shape of either a circle or a triangle, and its color was either red or green. Participants were instructed to use two response keys to indicate whether the color was red or green if the cue was color, and whether the shape was a circle or triangle when the cue was shape. There were 80 trials in total. | IES difference between “switch” and “no-switch” trials |
|                      | **Category switch** On each trial a fixation cross (600 ms) was followed by a cue (either a cross or a heart; 200 ms), a blank-screen CSI with variable duration, and a stimulus word describing an object (1,500 ms). There were two response keys. When the cue was a cross, the instruction was to indicate whether the described object was smaller or larger than a soccer ball. When the cue was a heart, the instruction was to indicate whether the object was animate or inanimate. There were four blocks (each 32 trials) in this task: CSIs were short (200 ms) in the first and third block, and long (1,000 ms) in the second and fourth block. For the current study, only the 64 short-CSI trials were analyzed. | IES difference between switch and no-switch trials |
| **Updating**         | **2-back** Throughout the task eight circles arranged around the screen center were shown. For the first 1,500 ms of each trial all circles were empty. Then one of the circles was filled out for 500 ms, giving the impression that it flashed. Participants were instructed to press the right key when the flashing circle was the same one that had flashed two trials earlier (“yes” trials), and to press the left key otherwise (“no” trials). There were 40 “yes” and 120 “no” trials. | IES across all trials |
|                      | **Letter memory** On each of the 18 trials, a sequence of either five, seven, or nine consonants was shown in the screen center. A fixation cross was shown for 2,000 ms before each letter, and each letter was shown for 2,000 ms. Participants then had to enter the last three letters of the sequence on the keyboard. Speeded responses were not required. | ER across all trials |

(Continues)


2.3.3 Structural equation models predicting self-control

Two SEMs were built by extending the selected measurement model to test hypotheses regarding interactions of GEF and chronic stress on desire regulation and the efficacy of resistance. Because Mplus does not provide standardized coefficients for interactions involving latent factors, we report unstandardized coefficients for these models. However, coefficients are well interpretable since the variance of GEF was fixed at 1 and TICS-SSCS scores were standardized prior to model calculation.

The purpose of the first SEM (SEM1) was to test hypothesis 1 that chronic stress moderates the impact of GEF on desire regulation. This SEM was constructed by regressing the Level-1 variable desire strength on the Level-2 predictors GEF, TICS-SSCS and their interaction term. Desire strength was not centered since it was the dependent variable in this model. All situations where a conflict-laden desire was reported was different from the preceding trial and “no-switch” trials (where the task set was the same as in the preceding trial). Although not commonly used as an updating task in latent variable models of executive functioning, the AX-CP task requires continually maintaining and updating context information in working memory.

3 RESULTS

3.1 Chronic stress

Participants’ TICS-SSCS scores ($M = 13.4; SD = 7.39$) were in line with results from the corresponding cohort (aged 14 to 44) of a healthy German reference sample ($M = 14.4; SD = 8.31; Petrowski et al., 2012$). Internal consistency was good (Cronbach’s $\alpha = .88$) and comparable to the reference sample (.91).

3.2 Real-life self-control

Experience sampling data were unavailable for eight participants due to technical problems. Descriptive statistics for the remaining 330 participants are presented in Table 5. The path model of self-control is summarized in Figure 1. As expected, resistance had a strong negative effect on enactment ($B_{log} = −3.24$, $p < .001$). Desire strength was not significantly related to resistance ($B_{log} = −0.07$, $p = .090$), and had no direct effect on enactment ($B_{log} = −0.02$, $p = .881$). However, desire strength moderated the effect of resistance on enactment insofar as the negative effect of resistance on enactment was attenuated for stronger desires ($B_{log} = 0.54$, $p < .001$). Conflict strength was positively related to resistance ($B_{log} = 0.86$, $p < .001$; that is, resistance was attempted more often when conflict was strong). Furthermore, conflict strength had a direct negative
**TABLE 3** Descriptive statistics and reliabilities of executive function task outcomes

| Task/Scale          | Observations | Distribution measures (after trimming) | Reliability<sup>d</sup> |
|---------------------|--------------|----------------------------------------|-------------------------|
|                     | Included     | Excluded<sup>a</sup> | Missing<sup>b</sup> | Trimmed<sup>c</sup> | M (SD) | Min. | Max. | Skewness | Kurtosis |            |
| Go-nogo             | 338          | –                        | –                   | 8                     | 394 ms (86) | 281  | 671  | 1.47     | 2.13     | .81         |
| Stop signal         | 325          | 13                       | –                   | 1                     | 182 ms (50) | 61   | 336  | .07      | −.22     | .59         |
| Stroop<sup>e</sup>  | 335          | 2                        | 1                   | 3                     | 63 ms (37)  | 0    | 177  | .78      | .70      | .53         |
| Number-letter<sup>e</sup> | 332      | 6                        | –                   | 5                     | 332 ms (203)| 0    | 963  | 1.11     | 1.24     | .82         |
| Color-shape<sup>e</sup> | 334      | 4                        | –                   | 5                     | 109 ms (82) | 0    | 371  | 1.13     | 1.21     | .64         |
| Category switch<sup>e</sup> | 327      | 11                       | –                   | 6                     | 81 ms (87)  | 0    | 355  | 1.40     | 1.52     | .68         |
| 2-back              | 321          | 17                       | –                   | 5                     | 549 ms (172)| 288  | 1,089| .99      | .74      | .88         |
| Letter memory<sup>f</sup> | 338      | –                        | –                   | 1                     | 0.43 (0.22) | 0    | 1.08 | −.18     | .13      | .61         |
| AX-CP<sup>g</sup>   | 336          | 2                        | –                   | 3                     | 368 ms (55) | 237  | 534  | .60      | .50      | .69         |

Abbreviations: Max., maximum; Min., minimum.

<sup>a</sup>Observations were excluded when the binomial probability of achieving the observed accuracy in the critical condition by random responding was >.05. For the stop signal task, lenient exclusion criteria proposed by Congdon et al. (2012) were applied.

<sup>b</sup>Missing due to technical problems.

<sup>c</sup>For each task, Observations that deviated from the group mean by more than three SDs were replaced with values 3 SDs from the mean to improve normality.

<sup>d</sup>Internal consistency was calculated by adjusting split-half correlations with the Spearman-Brown prophecy formula.

<sup>e</sup>Difference scores (Stroop interference and switch cost, respectively) were replaced with 0 when negative.

<sup>f</sup>Accuracy scores were arcsine transformed to improve normality.

<sup>g</sup>IESs could not be calculated for two participants who had no correct BX trials. These observations were assigned the post-trimming maximum (534 ms).
effect on enactment ($B_{\log} = -0.67, p < .001$; that is, more conflict-laden desires were less often enacted), but did not interact with resistance ($B_{\log} = 0.02, p = .911$). Associations between resistance, desire strength, conflict strength, and enactment are illustrated in Figure 2. Desire strength and conflict strength were not significantly correlated ($r = .02, p = .502$).

### 3.3 Executive functioning

Descriptive statistics for EF task outcomes are shown in Table 3. Appendix B (Table B1) provides maximum-likelihood estimates of correlations between task outcomes. The measurement model with three correlated first-order latent factors showed acceptable fit to the data (CFI = .930, RMSEA = .041), and significantly better fit than alternative models covered by Karr et al. (2018; see Table 4 for a summary). Extended by the second-order factor GEF, this model served as the basis for all subsequent SEMs. The second-order factor model is shown in Figure 3. A nested factor model did not converge in our sample, although the nested model was found to best fit summary data in Karr et al.’s (2018) re-analysis of latent variable studies. Note, however that this was only found when excluding samples where the nested model did not converge (as is the case here).

### 3.4 Structural equation models

SEMs related to a-priori hypotheses are summarized in Tables 7 and 8. SEM 1 (Table 7) showed that chronic stress in terms of TICS-SSCS scores had a positive main effect on desire strength in conflict situations ($B = 0.09, p = .011$), whereas the negative main effect of GEF on desire strength was not significant ($B = -0.10, p = .126$). Importantly, chronic stress and GEF significantly interacted as predicted by hypothesis 1 ($B = 0.13, p = .007$): GEF had a less negative effect on desire strength among more stressed participants. Relations between chronic stress, GEF, and desire strength are illustrated in Figure 4.

Consistent with the path model of self-control, SEM 2 (Table 8) showed that in situations where resistance was attempted, enactment was positively predicted by desire strength ($B_{\log} = 0.54, p < .001$) and negatively predicted conflict strength ($B_{\log} = -0.82, p < .001$). Chronic stress and GEF had no significant main effects on enactment and no significant cross-level interactions with conflict strength. Contrary to the prediction of hypothesis 2, the interaction between chronic stress and GEF did not significantly predict enactment ($B_{\log} = 0.10, p = .680$).

| Occasions | N (per participant) | Desire strength | Conflict strength |
|-----------|---------------------|-----------------|------------------|
|           | M  | SD  | M  | SD  | M  | SD  |
| Alarm issued | 18,480 | 56 | –  | –   | –  | –   |
| Alarm accepted | 14,471 (78.3%) | 43.85 | 8.98 | – | – | – |
| Desire | 10,435 (56.5%) | 31.62 | 10.12 | 4.26 | 1.10 | 3.86 | 1.43 |
| Conflict | 3,679 (19.9%) | 11.15 | 7.37 | 4.21 | 1.09 | 3.86 | 1.43 |
| Resistance | 2,480 (13.4%) | 7.52 | 5.76 | 4.23 | 1.08 | 4.33 | 1.27 |
| Enactment | 824 (4.5%) | 2.50 | 2.86 | 4.51 | 1.06 | 3.75 | 1.25 |
| No enactment | 1,656 (9.0%) | 5.02 | 4.22 | 4.10 | 1.07 | 4.62 | 1.17 |
| No resistance | 1,199 (6.5%) | 3.63 | 3.59 | 4.16 | 1.09 | 2.88 | 1.26 |
| Enactment | 1,138 (6.2%) | 3.45 | 3.56 | 4.15 | 1.10 | 2.83 | 1.22 |
| No enactment | 61 (0.3%) | 0.18 | 0.49 | 4.39 | 1.10 | 3.90 | 1.56 |

Note: Data from 330 participants for whom experience sampling data were available. Eight participants did not report conflicts.
and had no significant impact on the effect of conflict strength on enactment ($B_{\log} = -0.06, p = .707$). The same pattern was found in an ancillary model (Table 8) including all conflict situations (irrespective of attempted resistance).

GEF was not significantly correlated with TICS-SSCS scores ($r = -.04; p = .684$).

### 3.4.1 Exploratory models

Several exploratory SEMs are reported in Appendix C. Table C1 reports SEMs corresponding to SEMs 1 and 2, but with the first-order factors Inhibition, Shifting, and Updating in place of GEF).

To assess associations of chronic stress and executive functioning with attempted resistance, the binary Level-1 variable resistance was regressed on TICS-SSCS, GEF, and their interaction. All situations where a conflict was reported were included in this model (Table C2). In accordance with the path model of self-control, conflict strength had a strong positive main effect on resistance ($B_{\log} = 1.16, p < .001$). Moreover, a significant cross-level interaction between conflict strength and GEF was found ($B_{\log} = 0.23, p = .017$): The positive relationship between conflict strength and resistance was more pronounced among participants with stronger GEF. There were no significant effects of chronic stress on resistance.

To see whether chronic stress and GEF predicted the occurrence of self-control conflicts (which can be interpreted as a marker of preventive self-control), the binary Level-1 variable conflict was regressed on TICS-SSCS, GEF, and their interaction. All situations where an alarm was accepted (43.83 on average) were included in this model (Table C3). Upon accepting an alarm, more chronically stressed individuals were more likely to report a conflict ($B_{\log} = 0.18, p = .002$). Reporting a conflict was not significantly predicted by GEF ($B_{\log} = 0.06, p = .559$) or the interaction between TICS-SSCS and GEF ($B_{\log} = -0.07, p = .526$). A corresponding model predicting the binary Level-1 variable desire showed that reporting a desire (irrespective of conflict) was not significantly associated with chronic stress levels ($B_{\log} = 0.04$).

### TABLE 6 Summary of the path model of self-control

| Prediction of resistance | $B_{\log}$ or $r$ | 95% Confidence interval | $p$ |
|--------------------------|-------------------|-------------------------|-----|
| Intercept                | 0.89              | [0.73, 1.04]            | <.001 |
| Desire strength          | -0.07             | [-0.15, 0.01]           | .090 |
| Conflict strength        | 0.86              | [0.77, 0.96]            | <.001 |

| Prediction of enactment | $B_{\log}$ or $r$ | 95% Confidence interval | $p$ |
|-------------------------|-------------------|-------------------------|-----|
| Intercept               | 2.67              | [2.35, 2.99]            | <.001 |
| Desire strength         | -0.09             | [-0.40, 0.22]           | .568 |
| Conflict strength       | -0.67             | [-0.97, -0.37]          | <.001 |
| Resistance              | -3.24             | [-3.57, -2.91]          | <.001 |
| Resistance $\times$ desire strength | 0.54 | [0.18, 0.89] | .003 |
| Resistance $\times$ conflict strength | 0.02 | [-0.29, 0.33] | .911 |

| Correlation             | $r$               | 95% Confidence interval | $p$ |
|-------------------------|-------------------|-------------------------|-----|
| Desire strength with conflict strength | .02 | [-.03, .06] | .502 |

**Note:** Model based on data from 322 participants for whom experience sampling data were available and who reported conflicts. Coefficients are non-standardized. $p$-values are two-tailed.

**FIGURE 1** Summary of the path model of self-control. Arrows directed at other arrows represent interactions. Numbers on directed arrows are non-standardized logistic regression coefficients. Effects of resistance, desire strength, and conflict strength on enactment are illustrated in Figure 2.
**FIGURE 2** Interaction plots illustrating effects of resistance, desire strength, and conflict strength on desire enactment. Log-odds were transformed to probabilities to improve interpretability. X-axes cover the range of person-mean centered desire strength and conflict strength from the 5th to the 95th percentile. Resistance had a strong negative main effect on enactment ($B_{\log} = -3.24$, $p < .001$). Desire strength had no main effect on enactment, but interacted strongly with resistance in that the effect of resistance on enactment was smaller for stronger desires ($B_{\log} = 0.54$, $p < .001$). Conflict strength did not interact with resistance but had a strong main effect on enactment ($B_{\log} = -0.67$, $p < .001$): Enactment was less likely for stronger conflicts, regardless of whether or not resistance was attempted.

**FIGURE 3** Summary of the second-order-factor measurement model which served as the basis for subsequent SEMs. Observed variables are depicted as rectangles, latent variables as ellipses, and residuals as circles. Numbers on arrows are standardized factor loadings, and numbers in circles are residual variances. All parameters were significant ($p < .001$).
\[ p = .478 \), GEF \((B_{\text{log}} = -0.02, p = .804)\), or the interaction thereof \((B_{\text{log}} = -0.01, p = .953)\).

4 | DISCUSSION

The present study aimed to investigate how chronic stress affects the use of cognitive control for self-control in real-life situations. We hypothesized that self-control in chronically stressed individuals is characterized by a lower impact of GEF, that is, individual differences in cognitive control abilities, on (1) desire regulation and (2) the efficacy of resistance to desire. Consistent with hypothesis 1, we found that high chronic stress was associated with a less negative relation between GEF and the perceived strength of conflict-laden desires. Contrary to hypothesis 2, we found no evidence for effects of chronic stress and GEF on desire enactment in cases of attempted resistance. In addition to these main results, an exploratory analysis showed that chronic stress was associated with an increased incidence of conflict-laden desires. In the following, we discuss what these results may reveal about associations between chronic stress and the use of control abilities for reactive self-control at different stages of self-control episodes.

4.1 | Evidence for increased reward sensitivity and impaired desire regulation under chronic stress

We found that chronic stress predicted the perceived strength of desires in two ways: First, we found a positive association between chronic stress and desire strength. This is consistent with the view that stress can increase reward salience by modulating dopaminergic brain regions, thereby amplifying the subjective value of immediate rewards (Maier et al., 2015; Mather & Lighthall, 2012; Starcke & Brand, 2016). Given that self-control demands can themselves be a source of stress (Nielsen et al., 2020; Schmidt & Neubach, 2007), our finding of a direct association between chronic stress and desire strength may reflect a bidirectional causal relationship between the two.

Second, as hypothesized, higher chronic stress was associated with a less negative relationship between GEF and desire strength: GEF was negatively related to desire strength only among less-stressed individuals. As we elaborate below, this interaction may suggest that chronic stress impairs desire regulation via a reduced use of cognitive control. Importantly, TICS-SSCS scores were not correlated with GEF, indicating that chronic stress is not associated with enduring impairments in cognitive control, but merely with a reduced employment of cognitive control processes in the service of reactive desire regulation. This is in line with the notion that

### TABLE 7 Summary of structural equation model 1 (prediction of desire strength)

| Predictor            | \( B \)   | \( 95\% \) Confidence interval | \( p \)  |
|----------------------|-----------|--------------------------------|--------|
| Intercept            | 4.19      | [4.12, 4.26]                   | <.001  |
| TICS-SSCS            | 0.09      | [0.02, 0.15]                   | .011   |
| GEF                  | -0.10     | [-0.23, 0.03]                  | .126   |
| TICS-SSCS × GEF      | 0.13      | [0.04, 0.22]                   | .007   |

*Note: Coefficients are non-standardized. \( p \)-values are two-tailed. All situations where a conflict was reported \((N = 3,679)\) were included in SEM 1.*

### TABLE 8 Summary of structural equation model 2 (prediction of desire enactment)

| Predictor            | Model SEM 2* | Ancillary modelb |
|----------------------|--------------|------------------|
|                      | \( B_{\text{log}} \) | 95% Confidence interval | \( p \) | \( B_{\text{log}} \) | 95% Confidence interval | \( p \) |
| Intercept            | -1.02        | [-1.20, -0.83]   | <.001  | 0.20      | [0.03, 0.36]   | .018   |
| Desire strength      | 0.53         | [0.38, 0.69]     | <.001  | 0.41      | [0.29, 0.53]   | <.001  |
| Conflict strength    | -0.82        | [-0.96, -0.68]   | <.001  | -1.20     | [-1.34, -1.07] | <.001  |
| TICS-SSCS            | -0.01        | [-0.20, 0.18]    | .920   | 0.05      | [-0.13, 0.22] | .587   |
| GEF                  | -0.23        | [-0.38, 0.09]    | .154   | -0.15     | [-0.49, 0.18] | .365   |
| TICS-SSCS × GEF      | 0.10         | [-0.38, 0.58]    | .680   | -0.06     | [-0.13, 0.22] | .821   |
| Conflict strength × TICS-SSCS | -0.01     | [-0.14, 0.12]   | .848   | 0.02      | [-0.11, 0.14] | .802   |
| Conflict strength × GEF | -0.06     | [-0.34, 0.23]   | .698   | -0.12     | [-0.33, 0.09] | .249   |
| Conflict             | -0.06        | [-0.48, 0.26]    | .707   | 0.06      | [-0.31, 0.42] | .757   |

*Note: Coefficients are non-standardized. \( p \)-values are two-tailed.

*All situations where resistance was reported \((N = 2,480)\) were included in SEM 2.

bAll situations where a conflict was reported \((N = 3,679)\) were included in the ancillary model.
self-control failures may often reflect a reduced mobilization of cognitive control rather than impaired control abilities (Krönke et al., 2018; Wolff et al., 2016). Note that we examined a sample of young adults here, and that TICS items refer only to stressful experiences in the three months preceding test administration. Our results are therefore reconcilable with the view that childhood and youth trauma or chronic stress prolonged over years can potentially disrupt brain development and may cause permanent structural and functional alterations in prefrontal cortex (Belleau, Treadway, & Pizzagalli, 2019; Romeo, 2017), whereas acute stress appears to have only nuanced effects on inhibitory control (Shields, Szama, & Yonelinas, 2016).

How could chronic stress-related reductions in the use of cognitive control lead to increased desire strength? As stated above, early reactive self-control involves several forms of emotion regulation (attentional deployment, reappraisal, and acceptance). A common feature of these regulatory mechanisms is that they often depend on cognitive control (Braunstein, Gross, & Ochsner, 2017; Ochsner, Silvers, & Buchle, 2012), rendering them less effective whenever control is suspended. This may indeed be the case under stress, which is known to affect brain networks involved in cognitive control and appears to promote habitual responding (Girotti et al., 2018; Hermans et al., 2014; Möschl, Walser, Plessow, Goschke, & Fischer, 2017; Starcke & Brand, 2016). Moreover, acute stress has been shown to result in a reduction of reward-related activation in the medial prefrontal cortex, while leaving intact reward-related responses in the ventral striatum (Ossewaarde et al., 2011). This may indicate that stress induces a shift from prefrontal valuation processes presumably reflecting higher-order goals toward ventral striatal processes reflecting responsivity to immediate reward (Schwabe, 2017). In this light, our finding that GEF abilities were less negatively related to desire strength among more stressed individuals may reflect stress-induced impairments in the use of cognitive control leading to desire regulation deficits.

So far, we have discussed evidence that chronic stress can increase reward salience and reduce desire regulation. How the resulting amplification of desire strength may affect self-control can be derived from our path model, and is illustrated in Figure 2: Unsurprisingly, and in line with previous findings (Hofmann, Adriaanse, Vohs, & Baumeister, 2014; Hofmann, Baumeister, et al., 2012), the negative relation between resistance and desire enactment was substantially moderated by desire strength, that is, strong desires were particularly “hard to resist.” Taken together with the assumed effects of stress on reward salience and desire regulation, this could explain why stress reduces self-control, as has been documented in a variety of domains including stress-induced eating (e.g., Adam & Epel, 2007; Sinha & Jastreboff, 2013), aggression (e.g., Sprague, Verona, Kalkhoff, & Kilmer, 2011), and problematic smartphone use (Van Deursen, Bolle, Hegner, & Kommers, 2015). The same link between stress and self-control may also apply to impulsivity in various mental health conditions where chronic stress is considered a central etiological factor (Ingram & Luxton, 2005). Of all mental disorders, addiction is most markedly characterized by repeated self-control failures (Bühringer, Wittchen, Gottlebe, Kufeld, & Goschke, 2008; Goschke, 2014; Kozak et al., 2018). Addiction-related cues are assigned excessive incentive salience by altered reward circuitry, giving rise to intense cravings (Robinson & Berridge, 2003). Stress often induces relapse by apparently amplifying these cravings (Sinha, 2008). Extrapolating from the present results, stress-induced relapse (and exacerbation of addictive disorders more generally) may reflect desire regulation deficits that are (partially) caused by stress-related impairments in the use of cognitive control. In addition, this mechanism may develop into an escalating feedback loop where chronic stress, desire regulation deficits, and repeated relapse are mutually amplified.

4.2 No evidence for stress-related impairments of resistance

Our path model of self-control (Figure 1) indicates that resistance strategies at later stages of the reactive self-control process were highly efficient in preventing the enactment of conflict-laden desires, especially when desire strength was low (which may be achieved by the application of earlier
desire regulation strategies). Contrary to our second hypothesis, we found no evidence for associations between chronic stress or GEF and desire enactment in situations where resistance was attempted. This suggests that late resistance strategies such as inhibiting or overriding desire enactment are less strongly associated with individual differences in chronic stress and GEF compared to early desire regulation strategies. This may be surprising insofar as the ability to inhibit or override responses is at the core of cognitive control (Miyake & Friedman, 2012). That we found no evidence for stress-related impairments in resistance is perhaps explained in part as a result of the multiple effects of stress on different brain systems: For instance, stress-induced decreases in cognitive control could be cancelled out by concurrent increases in salience processing (Hermans et al., 2014). In accordance with this idea, higher error-related brain activity in the salience network has been found to predict lower rates of desire enactment in real-life self-control situations (Krönke et al., 2018). Increased salience detection and performance-monitoring may cause stronger recruitment of cognitive control networks, which in turn leads to increased top-down modulation of neural value signals by long-term goals and, thus, less impact of immediate desires on behavioral choices (Krönke et al., 2020). Together with converging evidence that acute stress is associated with activation of the salience network, but not always with changes in the control network (Van Oort et al., 2017), our present findings are consistent with the idea that chronic stress does not primarily impair inhibitory self-control processes during acute conflicts, but rather increases the impact of immediate relative to anticipated desires on behavioral choices.

The same pattern of results, including no significant association between desire enactment and chronic stress, was found in an ancillary analysis where all conflict situations, irrespective of attempted resistance, were included in the model. Taken together with the exploratory result that reports of attempted resistance were not predicted by chronic stress (Appendix C), this suggests that chronic stress did not affect late self-control via a motivational pathway. The same exploratory analysis provided preliminary evidence that the positive association between conflict strength and attempted resistance is especially pronounced in individuals possessing strong GEF abilities. A similar result was reported in a previous experience sampling study (Hofmann et al., 2014), where high inhibitory control as measured with a Stroop task was found to be associated with a stronger positive effect of dietary restraint on attempted resistance to food cravings. These findings resonate with the view that one of the functions of cognitive control in reactive self-control is to modulate the weight of goal-related choice attributes in value-based decision making (Hare, Malmaud, & Rangel, 2011; Krönke et al., 2020), and may suggest that such modulation also affects valuation processes that determine the motivation to apply more effortful self-control strategies. Adding to existing models of self-control (e.g., Kotabe & Hofmann, 2015), motivation to exert control could be not only a prerequisite but also a consequence of control processes. Another (compatible) explanation for these results is based on the fact that, like real-life self-control, performance on executive function tasks inevitably should reflect not only cognitive control abilities but also motivation to mobilize control in response to conflict. Hence, GEF and attempting effortful resistance to real-life temptations may, at least to some degree, reflect the same motivational disposition.

4.3 | Does chronic stress impair preventive self-control?

In another exploratory analysis (Appendix C), we found an increased incidence of conflicts among more chronically stressed participants. This association was not found in a corresponding model predicting desires (irrespective of conflict), indicating a specific link of chronic stress with the incidence of conflict-laden desires. These results can be interpreted as evidence for stress-induced impairments in preventive self-control (Hofmann & Kotabe, 2012), that is, strategies used in order to not encounter problematic desires in the first place such as stimulus control (avoiding or constraining situations in such a way that the emergence of desires is impeded; Duckworth, Gendler, & Gross, 2016). Similarly, automatized aspects of the above-mentioned strategy of distraction, if applied early enough upon encountering a potentially tempting stimulus, may prevent desires from emerging into consciousness (Hofmann et al., 2015). This process may be hampered in chronically stressed individuals since chronic stress may increase salience processing, thus orienting attention toward reward-related stimuli (Mather & Lighthall, 2012). Increased salience processing under chronic stress may also induce an elevated sensitivity to the conflicting nature of experienced desires, potentially leading to more frequent reports of conflict-laden desires under chronic stress. An additional interpretation, which corresponds with the abovementioned possibility of a bidirectional causal relationship between chronic stress and self-control demands, is that the stress levels of individuals who experience many self-control conflicts are to some degree caused by these experiences themselves. Hypothesis-driven research is needed to further clarify the relationship between stress and preventive self-control.

4.4 | Evidence for low-effort conflict-driven self-control

Early self-control strategies that require timely detection of self-control conflicts, such as the desire regulation strategies
discussed above, are assumed to require less effort compared to late resistance strategies (de Ridder et al., 2018). This implies that the subjective experience of effort is not an essential component of conflict-driven self-control. In line with this, our path model (Figure 1) shows a strong direct negative effect of conflict strength on desire enactment in addition to the indirect effect that is mediated by resistance. At first glance, this finding appears to be at odds with results reported by Hofmann et al. (2012), who found that the effect of conflict on enactment was entirely mediated by resistance. However, this divergence may be explained by two small but important differences between these authors’ dataset/analysis and ours: First, whereas we measured the occurrence of conflict (Yes/No) and conflict strength (from 1, very weak, to 6, very strong) separately, they operationalized both within one conflict variable from 0 (no conflict at all) to 4 (very high conflict). Second, and relatedly, whereas our path model includes only situations where conflict was reported, their analyses also included conflict-free desires, which made up more than half of the data points. That most of the variance in Hofmann et al.’s (2012) conflict variable was between conflicts and non-conflicts may have concealed direct effects of conflict on desire enactment and, thus, inadvertently obscured evidence for types of conflict-driven self-control that circumvent the subjective experience of effortful resistance.

4.5 Limitations and generalizability constraints

Although the present results support our hypothesis that chronic stress impairs self-control by reducing the use of cognitive control for desire regulation, there are limitations regarding this interpretation. First, the correlational study design does not allow for conclusions regarding causal relations. This is a general downside of observational field studies (the upside being ecological validity). Another limitation that follows from our observational study design is the somewhat inferential operationalization of the efficacy of desire regulation (inferred from perceived desire strength) and resistance strategies (inferred from desire enactment in cases of resistance). Variability in desire strength and enactment may, indeed, reflect not only the efficacy of self-control strategies but also additional processes that are unrelated to self-control. We acknowledge that our hypothesis-centered interpretation of the present results in terms of causation and construct-relatedness can be challenged, and that alternative interpretations are conceivable. Our observational approach therefore needs to be complemented with (less ecologically valid) experimental studies that allow for stronger causal inferences and more controlled operationalization of constructs.

Our main results provide evidence that associations between chronic stress and the strength of conflict-laden desires, which may reflect early reactive self-control, are moderated by individual differences in executive functioning. Given that our participants were recruited from a representative community sample of young adults, and given that our experience sampling protocol was designed to capture a wide range of different desires, we expect our results to generalize to experience sampling of everyday self-control by young adults, irrespective of particular populations of participants or desire domains of interest. Since chronic stress was operationalized as inter- but not intra-individually variable, we do not have evidence that our findings generalize to observations of intra-individually varying chronic (or acute) stress. Considering that we used a self-report measure of chronic stress, and that there appears to be no strong relationship between self-reported chronic stress and hair cortisol as a retrospective marker of chronic stress levels (Weckesser et al., 2019), we do not expect our results to generalize to physiological or hormonal indicators of stress reactivity. We have no reason to believe that our results depend on other characteristics of participants, materials, or context.

5 Conclusion

The present study combined experience sampling of everyday self-control episodes with latent-variable models of individual differences in executive functioning to investigate how the use of cognitive control for self-control is related to chronic stress. Chronic stress was associated with increased desire strength as well as a less negative relation between GEF and desire strength. While our observational study design does not allow for causal inferences, these results may suggest that chronic stress can impair self-control by increasing reward salience while also reducing the use of cognitive control for early desire regulation strategies such as attentional deployment, reappraisal, or acceptance. In recent years, evidence has accumulated that preventive and early reactive self-control are more closely linked to successful goal pursuit and well-being than late reactive self-control (e.g., Milyavskaya & Inzlicht, 2017; Nielsen et al., 2019). This has contributed to a shift of interest from effortful resistance strategies to more automated strategies such as habits and routines as well as relatively low-effort “smart strategies” for reactive self-control (de Ridder et al., 2018). Our main results, providing evidence for associations of chronic stress with early, but not late, reactive self-control, together with the exploratory finding that stressed individuals reported more self-control conflicts, appear to underscore the relative unimportance of resistance to temptation. However, in line with previous experience sampling results (Hofmann, Baumeister, et al., 2012), we found that reporting effortful resistance strongly predicted non-enactment of conflict-laden desires. How could such a powerful predictor of situational self-control be
only relatively weakly related to successful long-term goal pursuit? One possible explanation is that resistance is not actually unimportant but merely less proximately related to goal attainment than, for instance, adaptive habits. After all, habits may be automatic and effortless once established, but to establish a new habit in the first place, or indeed to break an existing one (e.g., when attempting to quit smoking; Berkman, Falk, & Lieberman, 2011), should often require resistance to a series of momentary temptations. Another possible explanation is that resistance to temptation is indeed important for long-term goal pursuit, but depends substantially on the successful application of earlier self-control strategies such as reactive desire regulation. In line with this, and as previously reported by Hofmann, Baumeister, et al., (2012), we found that the negative effect of resistance on desire enactment was more pronounced when desire strength was low.

That successful resistance to temptation was predicted by neither chronic stress nor GEF or an interaction thereof is in line with results reported by Hofmann, Baumeister, et al. (2012), who found that inter-individual differences had a stronger impact on earlier components of self-control, whereas later components were more strongly affected by situational factors. Taken together, this may indicate that the efficacy of late self-control strategies such as inhibiting or overriding is, indeed, relatively unaffected by chronic stress or executive functioning. However, it would be premature to conclude from our results that individual differences in executive functioning do not affect the efficacy of late self-control. Given that inhibiting and overriding prepotent responses are core domains of cognitive control, it appears more likely that additional factors which were not considered in the present study such as self-efficacy (Bandura, Freeman, & Lightsey, 1997) or implementation intentions (van Koningsbruggen, Stroebe, Papies, & Aarts, 2011) moderate the use of control abilities for self-control. Our findings might suggest that such moderating factors can differ between early and late stages of self-control. Furthermore, an exploratory analysis yielded preliminary evidence that individual differences in executive functioning are reflected in the conflict-driven motivation to exert effortful self-control. Several studies have lately found weak or missing associations between laboratory measures of executive functioning and self-reports of real-life self-control (Allom, Panetta, Mullan, & Hagger, 2016; Duckworth & Kern, 2011; Eisenberg et al., 2019; Nečka, Gruszka, Orzechowski, Nowak, & Wójcik, 2018; Saunders, Milyavskaya, Etz, Randles, & Inzlicht, 2018). This has been attributed to potential psychometric issues (e.g., Enkavi et al., 2019; Hedge, Powell, & Sumner, 2018) as well as presumed non-overlap in constructs (e.g., Saunders et al., 2018; Wennenhold & Friese, 2020). The results of the present study point towards moderation by third variables such as chronic stress or conflict strength as an additional explanation for the empirically low correspondence between self-reported self-control and laboratory measures of individual differences in executive functioning: Whereas the highly controlled conditions in the laboratory should allow for somewhat robust assessment of cognitive abilities, the use of these abilities in uncontrolled real-life situations may more strongly depend on a multitude of personal and situational factors.

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CONFLICT OF INTEREST
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A

ADDICTION SYMPTOMS IN THE STUDY SAMPLE DIFFERENCES

Participants were recruited for three groups: A substance-related symptoms group (100 participants; two or more DSM-5 criteria for alcohol and/or tobacco use disorder), a non-substance-related symptoms group (118 participants; two or more DSM-5 criteria for gambling disorder and/or adapted criteria for addiction-like behaviors), and a control group (120 participants; maximum one criterion of any category). Table A1 summarizes the fulfillment of diagnostic criteria by study participants across the sample.

| Addictive disorder/behavior | Number of criteria fulfilled |
|-----------------------------|-----------------------------|
|                             | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
| Nicotine<sup>a</sup>               | 275| 8  | 12 | 17 | 12 | 6  | 4  | 4  | –  | –  |
| Alcohol<sup>b</sup>             | 200| 77 | 35 | 16 | 4  | 3  | 3  | –  | –  | –  |
| Gambling<sup>c</sup>            | 332| 5  | 1  | –  | –  | –  | –  | –  | –  | –  |
| Gaming<sup>d</sup>              | 297| 7  | 6  | 8  | 8  | 4  | 4  | 3  | 1  | –  |
| Internet use<sup>d</sup>         | 174| 63 | 26 | 36 | 20 | 11 | 5  | 1  | 1  | 1  |
| Compulsive buying<sup>d</sup>   | 336| 2  | –  | –  | –  | –  | –  | –  | –  | –  |

Note: According to DSM-5, a substance use disorder is diagnosed when 2 or more criteria are met, and substance use disorder severity is specified as either mild (2–3 criteria met), moderate (4–5), or severe (6 or more). Gambling disorder is diagnosed when 4 or more criteria are met, and gambling disorder severity is specified as either mild (4–5 criteria met), moderate (6–7), or severe (8–9).

<sup>a</sup>DSM-5 nicotine use disorder.
<sup>b</sup>DSM-5 alcohol use disorder.
<sup>c</sup>DSM-5 gambling disorder.
<sup>d</sup>These addiction-like behaviors are not recognized as addictive disorders according to DSM-5. Criteria were adapted from DSM-5 criteria for substance use disorders.

APPENDIX B

CORRELATIONS AMONG EXECUTIVE FUNCTION TASK OUTCOMES

| Task                          | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|-------------------------------|----|----|----|----|----|----|----|----|----|
| 1. Go-nogo                    | –  |    |    |    |    |    |    |    |    |
| 2. Stop signal                | .40|    |    |    |    |    |    |    |    |
| 3. Stroop                     | .24| .12|    |    |    |    |    |    |    |
| 4. Number-letter              | .12| .17| .09|    |    |    |    |    |    |
| 5. Color-shape switch         | .09| .12| -.05| .21|    |    |    |    |    |
| 6. Category switch            | .15| .03| .07| .26| .16|    |    |    |    |
| 7. 2-back                     | .13| .08| .05| .13| .03| .14|    |    |    |
| 8. Letter memory              | .18| .20| .17| .01| -.02| .06| .27|    |    |
| 9. AX-CP                       | .16| .07| .02| .09| .14| .19| .28| .20|    |

Note: Correlations are full-information maximum-likelihood estimates based on all included observations from all participants ($N = 338$).
APPENDIX C

EXPLORATORY STRUCTURAL EQUATION MODELS

| Model/Predictor | Model (first-order factor) | Inhibition | Shifting | Updating |
|-----------------|----------------------------|------------|----------|----------|
|                 | B or $B_{log}$ | B or $B_{log}$ | B or $B_{log}$ |
| Intercept       | 4.19 <.001 | 4.19 <.001 | 4.19 <.001 |
| TICS-SSCS       | 0.08 .015 | 0.09 .009 | 0.09 .007 |
| First-order factor | −0.02 .676 | 0.00 .984 | 0.13 .020 |
| TICS-SSCS × first-order factor | 0.08 .048 | 0.11 .047 | 0.07 .145 |

Prediction of desire strength (corresponding to SEM 1)$^a$

Prediction of enactment (corresponding to SEM 2)$^b$

Note: Coefficients are non-standardized. $p$-values are two-tailed.

$^a$All situations where a conflict was reported ($N = 3,679$) were included in these SEMs.

$^b$All situations where resistance was reported ($N = 2,480$) were included in these SEMs.

### TABLE C2  Summary of structural equation model predicting attempted resistance

| Predictor          | $B_{log}$ | $p$   |
|--------------------|-----------|-------|
| Intercept          | 1.14      | <.001 |
| Desire strength    | −0.08     | .141  |
| Conflict strength  | 1.16      | <.001 |
| TICS-SSCS          | −0.04     | .590  |
| GEF                | 0.10      | .515  |
| TICS-SSCS × GEF    | 0.12      | .392  |
| Conflict strength × TICS-SSCS | −0.03 | .664  |
| Conflict strength × GEF | 0.23 | .017  |
| Conflict strength × TICS-SSCS × GEF | −0.04 | .790  |

Note: Coefficients are non-standardized. $p$-values are two-tailed. All situations where a conflict was reported ($N = 3,679$) were included in these models.

### TABLE C3  Summary of structural equation models predicting the occurrence of conflict and desire

| Predictor          | Conflict | $B_{log}$ | $p$   |
|--------------------|----------|-----------|-------|
| Intercept          | −0.72    | <.001     | 1.12  | <.001 |
| TICS-SSCS          | 0.18     | .002      | 0.04  | .478  |
| GEF                | 0.06     | .559      | −0.02 | .804  |
| TICS-SSCS × GEF    | −0.07    | .526      | −0.01 | .953  |

Note: Coefficients are non-standardized. $p$-values are two-tailed. All situations where an alarm was accepted ($N = 14,471$) were included in these models.