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How to assess negative affective reactivity to daily life stress in depressed and nondepressed individuals?

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ABSTRACT

Intensive longitudinal data studies on affective reactivity to daily life stress have used various dimensions of stress. Based on an evidence-based conceptual model of stress, the current study included unpredictability, uncontrollability and unpleasantness, and examined whether and how these predict affective reactivity in depressed and non-depressed individuals in daily life. Participants (27 depressed, 27 non-depressed) completed a diary 3 times a day for a period of 30 days. Multilevel analyses were performed to investigate unpleasantness, uncontrollability and unpredictability of daily events as univariate predictors of negative affect (NA). Multivariable models were composed to determine the optimal combination of stress dimensions, and whether the strength of the predictions differed between the depressed and non-depressed groups. Unpleasantness, uncontrollability and unpredictability each predicted subsequent NA independently. However, a combination of all three dimensions, together with an interaction between unpleasantness and uncontrollability, predicted subsequent NA best. The stress dimensions predicted NA more strongly in the depressed than the non-depressed group. This was mostly accounted for by an increased NA response to unpleasantness. Thus, unpleasantness seems to be the most important aspect of daily stress to distinguish depressed from non-depressed individuals. Nevertheless, for a comprehensive assessment of affective reactivity, a multidimensional model of event stressfulness is recommended.

1. Introduction

The experience sampling method is a structured diary technique that allows for frequently repeated sampling of affect, thoughts and experiences, with the purpose to investigate temporal dynamics and relationships in a naturalistic setting (Myin-Germeys et al., 2009), resulting in intensive longitudinal data (ILD). Studies utilizing ILD have indicated that stressful events in daily life increase subsequent negative affect (Affleck et al., 1994; Bolger et al., 1989; DeLongis et al., 1988; Johnson et al., 2008; Peeters et al., 2003; Schneiders et al., 2006; van Eck et al., 1998). Furthermore, several studies have found that depressed individuals show increased affective reactivity to daily life stress compared to non-depressed individuals (Myin-Germeys et al., 2003; van Winkel et al., 2015; Wichers et al., 2009), although one other study reported the opposite (Peeters et al., 2003). In non-clinical studies, a relationship between depressive symptoms and increased affective reactivity was found as well (South and Miller, 2014; Booij et al., 2018). These findings suggest that increased negative affective reactivity in response to daily events is a vulnerability marker for depression (Wichers et al., 2007), and it has been proposed to be causally related to the development of psychopathological symptoms as well (Myin-Germeys et al., 2003).

ILD studies investigating the relationship between stressful events in daily life and negative affect (in depressed or non-depressed individuals) used various dimensions to operationalize stressful events. These dimensions are subject to appraisal (e.g. an evaluation regarding the significance of events and event characteristics for well-being), which can elicit affective responses. The most commonly investigated

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dimension is the extent to which an event is experienced as unpleasant, an indicator of stressor intensity (Koolhaas et al., 2011; van Eck et al., 1998). Whereas some studies used unpleasantness solely (Wichers et al., 2007), or unpleasantness combined with importance and perceived stressfulness of an event (Peeters et al., 2003; van Winkel et al., 2015), others included the dimensions expectedness (e.g. to what extent an event was expected; Schneiders et al., 2006), and experienced control (Bylsma et al., 2011; van Eck et al., 1998). Hence, different measures have been used, some indicators of stressor intensity which are more generic (i.e. unpleasantness, stressfulness), and others that quantify the specific characteristics of events that contribute to perceived stressfulness (expectedness, experienced control). The diversity in stress measures complicates the synthesis of findings across studies. Although relatively generic measures can give insight into the degree to which an event is perceived as stressful, they do not give full insight into how specific characteristics of stressful events relate to affective reactivity. Moreover, the selection of stress dimensions in previous ILD studies was not yet firmly grounded in conceptual models of event stressfulness. Because to date it seems to be unclear how stressful events in daily life can be measured best, this needs to be systematically investigated by using dimensions derived from evidence-based models. This will provide future ILD studies with a validated conceptualization of stress, which can potentially aid synthesis of findings across studies.

First of all, the importance of controllability and predictability of aversive events in determining the behavioral stress response has been long recognized (Folkman, 1984; Mason, 1968; Seligman et al., 1971; Stern et al., 1982). Seligman et al. (1971) even argued that these two aspects, rather than the aversive events per se, may explain why some individuals develop peculiarities, illnesses and anomalies (such as depression) after stressful events, while others do not. This notion is supported by research into stressful life events and illness (Stern et al., 1982). In a highly influential conceptual review paper, Koolhaas et al. (2011) focused on controllability, predictability and stressor intensity as key determinants of the behavioral and physiological stress response. Building on this work, Peters et al. (2017) highlighted the importance of the state of uncertainty in an individual for the conceptualization of stress and stress-related illness, with a strong emphasis on controllability and predictability of threat in the environment.

As reviewed by Koolhaas et al. (2011), physiological studies support the importance of controllability and predictability as determinants of the stress response and adaptation. These stress dimensions have distinct physiological characteristics (de Boer et al., 1990; Weiss, 1972). Unpredictable stressors have been linked to the absence of an anticipatory physiological stress response. Moreover, uncontrollable stressors have been associated with reduced recovery of the physiological stress response. If a stressor is fully unpredictable, there is no opportunity for an individual to anticipate, prepare or avoid. In contrast, if no control can be exerted over the stressor, external factors determine the course and outcome of a hazardous situation. Consistent with experiments in animals, reduced recovery of stress hormones has also been found to predict negative (mental health) outcomes 3 years later in human adolescents (Nederhof et al., 2015). In addition to uncontrollability and unpredictability, Koolhaas et al. (2011) identified a third dimension to play a key role in the stress response, namely stressor intensity. This stress dimension captures the aversiveness of a stressor in a quantitative manner, as can be reflected in perceived threat or unpleasantness (Koolhaas et al., 2011; van Eck et al., 1998). The aversiveness of an event evokes a stress response, and the nature of this stress response may vary depending on how predictable or controllable the particular event is. Taken together, predictability, controllability and unpleasantness can be viewed as core features of the stress concept.

The present study aims to use the abovementioned conceptualization of stress, including unpredictability (of event occurrence as well as event outcome), uncontrollability of the event, and stressor intensity (Koolhaas et al., 2011), to investigate negative affective reactivity to daily events. Based on the literature, it was hypothesized that all three stress dimensions are positively associated with subsequent negative affect, and that unpleasantness, as being a more quantitative dimension, would show the strongest association (Koolhaas et al., 2011).

Furthermore, possible interactions between the stress dimensions of interest were explored. While previous studies investigated stress dimensions separately, it was considered important to additionally explore the possibility of non-cumulative effects, because complex relationships between controllability, stressors, and stress responses have been reported (De Berker et al., 2016; Folkman, 1984; Koolhaas et al., 2011). However, no clear-cut hypotheses regarding interactions could be formulated based on literature.

Finally, the model containing the optimal combination of stress dimensions (selected based on the goodness of fit relative to model parsimony) was used to evaluate the hypothesis that depressed individuals would show increased negative affective reactivity to stress compared to non-depressed individuals, on each of the included stress dimensions. When studying affective reactivity to daily life stress, controlling for negative affect prior to the daily stressful event is important. First of all, current negative affect can be influenced by prior negative affect (i.e. autocorrelation), especially in depressed individuals. Further, negative affect may bias event appraisal (Lazarus and Folkman, 1984; Mehu and Scherer, 2015). Because prior NA potentially confounds the relationship between daily life stress and subsequent NA, prior NA was explicitly modeled in the analyses.

2. Methods

2.1. Participants

The sample was drawn from the 'Mood and movement in daily life' (MOOVD) study, which was designed to investigate the dynamic relationship between physical activity and mood in daily life, and the role of several biomarkers therein. Participants (aged 20–50 years) were ambulatory monitored three times a day for 30 days, by means of electronic diaries, actigraphy, and saliva sampling, resulting in a total of 90 measurements per individual. For the present study, the electronic diary data was used. A detailed description of the study procedure was given in Booij et al. (2015).

Inclusion criteria for depressed participants were a diagnosis of Major Depressive Disorder (current episode or in remission for no longer than 8 weeks) verified with the Composite International Diagnostic Interview (WHO CIDI, 1990), and a Beck Depression Inventory (BDI-II; Beck et al. 1996) score > 14. This score was based on the standardized cut-off score specified in the BDI-II manual (Beck et al., 1996). It was used as a cut-off in previous studies including participants with depression (Booij et al., 2015, Penninx et al., 2008). Non-depressed individuals were included if they had a BDI-II score <9 and were free of mood disorders at the time of inclusion. Exclusion criteria were a current or recent (within the last 2 years) psychotic or bipolar episode, pregnancy and significant hearing or visual impairments. The CIDI and the BDI-II were administered by trained doctoral and postdoctoral level researchers. Groups were matched on gender, smoking, age, and BMI. Participants received a minimum of €60 for participation, and additional bonus fees according to the number of completed daily questionnaires. Finally, the participants received a personalized report on their daily mood and activity patterns within 3 months after the end of the study. The MOOVD design was approved by the responsible Medical Ethical Committee and all participants provided written consent before inclusion. Whereas initially 62 participants were enrolled, 4 participants discontinued participation and an additional 4 participants had too few valid measurements ($T < 60$) due to non-compliance, technical problems, or protocol violations. Data from 27 depressed and 27 non-depressed participants could be included for analysis. The sample consisted primarily of women (74.1%) with a mean age of 34.7 (sd = 9.9) in the depressed participant group and

mean age of 34.0 (sd = 9.0) in the non-depressed participant group. In the non-depressed participant group one participant had been depressed, 7 years before the time of the inclusion.

2.2. Ambulatory sampling

The participants completed questionnaires on an electronic diary, the PsyMate® (PsyMate BV, Maastricht, The Netherlands) (Myin-Germeys et al., 2011) for a period of 32 days, of which the first two days served to get familiar with the device. The PsyMate was programmed to generate beeps at three predetermined moments a day at equidistant time points: in the morning (mean ≈ 10 AM), 6 h later in the afternoon (mean ≈ 4 PM) and again 6 h later in the evening (mean ≈ 10 PM). This time-contingent approach was chosen to allow the application of time-series analysis. After every alarm beep, participants filled out the electronic diary. They were instructed to do so immediately after the beep, but a delay of maximally 1 h was allowed. On average, participants had 6.9 (7.7%) missing values for the diary variables.

2.3. Measures

2.3.1. Depression

Diagnosis of Major Depressive Disorder was verified with the CIDI and the BDI-II. The CIDI is a comprehensive structured interview frequently used in research to assess mental disorders according to the definitions and criteria of the DSM-IV (WHO CIDI, 1990). The instrument has good to excellent Kappa coefficients for most diagnostic sections (Wittchen, 1994). The BDI-II is a well-validated self-report measure including 21 items on affective and somatic depression symptoms, which are scored on a scale ranging from 0 to 3, with higher scores representing greater severity of symptoms (BDI-II; Beck et al., 1996). The internal consistency was described as around 0.9 and the retest reliability ranged from 0.73 to 0.96 (Wang and Gorenstein, 2013). Coefficient alpha for the BDI-II (α = 0.91) is high (Beck et al., 1996).

2.3.2. Negative affect

Negative affect scores were computed from mood items adopted from Bylsma et al. (2011), rated on a 7-point Likert scale, ranging from 1 (“not”) to 7 (“very”). The negative affect scale reflected the average of the items tense, anxious, distracted, restless, irritated, depressed, and guilty. Bylsma et al. reported a multilevel reliability estimate of >0.90 for NA.

2.3.3. Daily life stress

At each beep, participants rated 5 items regarding the most important event that happened since the previous assessment point. The item *How pleasant was this event?* was scored on a 7-point scale ranging from −3 *very unpleasant* to +3 *very pleasant.* The items *The event happened unexpectedly* (onset expectancy)*; The event went as expected* (outcome expectancy)*;* and *I had control over the situation* (controllability) were rated on a 7-point scale ranging from 1 *not at all* to 7 *very.* Onset expectancy and outcome expectancy were merged into the variable ‘unpredictability’, since both concern the prediction of an event, either the onset or the outcome of it (Koolhaas et al., 2011). Responses were recoded to allow high scores to reflect high perceived stress.

2.3.4. Negative affective reactivity

Negative affective reactivity was operationalized as the association between negative affect and stressfulness (measured in terms of unpleasantness, uncontrollability and unpredictability) of the most important event since the previous assessment point.

2.3.5. Person characteristics

Age, gender, completed education (0 = primary education, 1 = lower secondary education, 2 = higher secondary education/vocational education, 3 = university/college education), BMI, and smoking status (0 = non-smoking, 1 = smoking) were all based on self-report. DSM-IV diagnosis for determining eligibility, and information regarding previous depressive episodes were obtained from the CIDI interview. Medication use was assessed at the start and the end of the study, and covered (regular) medication use throughout the study period.

2.4. Statistical analysis

By design, intensive longitudinal data have a hierarchical structure; multiple observations (level 1) are nested within individuals (level 2). This requires the use of multilevel modeling procedures, which take the clustering of data into account and are also able to handle missing data without excluding cases (Snijders and Bosker, 2000). The negative affect (NA) and daily life stress variables were measured at the observation level, whereas person characteristics were measured at the individual level. Time-varying predictor variables were person-mean centered to reflect within-individual deviations from the person mean (Curran and Bauer, 2012; Bolger and Laurenceau, 2013). In addition, because increases or decreases in measurements over time may induce spurious associations, time-varying predictors were detrended as well (Rovine and Walls, 2006). To this end, we regressed these variables on a variable denoting the time points and saved the residuals. This was done for each individual separately. These residuals reflect the deviations of the scores from each individuals’ trend over time.

First, the effect of prior NA on unpleasantness, uncontrollability and unpleasantness was investigated in order to explicitly test whether prior NA influences event appraisal. A lagged $t-1$ NA variable (person-mean centered) was included as a predictor in the successive models, to model lag-1 autocorrelation and to control for a potential confounding effect of prior NA (Bolger and Laurenceau, 2013).

Second, the relationship between the stress dimensions and subsequent NA was tested by means of three univariable multilevel models. Unpleasantness, uncontrollability and unpredictability were included as the predictor variable, respectively, and NA was included as the dependent variable. Because NA was not normally distributed, confidence intervals were bootstrapped, using 1000 bootstrap samples.

Third, to evaluate the unique contributions of the stress dimensions to the prediction of negative affective reactivity, multivariable analyses were performed. Hence, unpleasantness, uncontrollability, and unpredictability were all included as predictor variables, as well as the two- and three-way interactions between these predictors. Only significant interaction effects were maintained in the final model. The models were compared using the Akaike Information Criterion (AIC), in view of its sensitivity to explained variance without explicitly favoring a parsimonious model. In addition, we inspected the Bayesian Information Criterion (BIC) to aid interpretation.

Fourth, to assess differences in NA reactivity between the depressed and non-depressed groups, the stress dimensions of the best model and interactions between these dimensions and depression status were investigated (i.e. whether depression status influences the association between unpleasantness and NA reactivity). In order to aid interpretation of a significant interaction effect, the relationship between the stress dimensions and NA was visualized according to the procedure described in Preacher, Curran and Bauer (2006), and examined separately for the depressed and non-depressed group in post-hoc analyses.

We added dummy variables for morning and afternoon as fixed and random factors to all models, to account for structural daytime differences in levels of negative affect. A random intercept and random slopes for the time-varying predictor variables NA($t-1$) and the stress dimensions were included to account for between-subject variability in the effects. Models with different covariance structures for the random effects and for the error-covariance matrix were fitted using restricted maximum likelihood estimation and the most optimal model was chosen based on the Akaike Information Criterion (AIC). For all models, the variance components structure for the random effects and an

Table 1
Characteristics of depressed and non-depressed groups.

Characteristics	Depressed$N$ = 27Mean (SD)	Non-depressed$N$ = 27Mean (SD)
Demographic		
Gender (female)	20 (74.1%)	20 (74.1%)
Age	34.7 (9.9)	34.0 (9.0)
BMI	24.2 (5.9)	22.5 (2.6)
Smoking status (% smoking)	25.9	22.2
Highest completed education (0–4)	2.4 (0.5)	2.5 (0.5)
Clinical		
BDI	31.3 (10.0)	2.7 (2.7)
Antidepressant medication[a]	12 (44.4%)	0 (0%)
Diary measures		
Unpleasantness (1–7)	3.5 (0.7)	2.8 (0.6)
Uncontrollability (1–7)	3.6 (0.8)	2.9 (0.8)
Unpredictability (1–7)	3.2 (0.6)	2.8 (0.6)
NA (1–7)	3.1 (1.0)	1.5 (0.5)

Abbreviations: NA = negative affect.
[a] Not including antipsychotics or Saint John's wort.

independent error-covariance structure resulted in the most optimal model. The final models were estimated with maximum likelihood estimation. Models were calculated using SPSS Statistics 22. In all analyses, a p value <0.05 was considered statistically significant.

3. Results

3.1. Group characteristics

Demographic and clinical characteristics of the 27 depressed and 27 non-depressed participants are displayed in Table 1. There were no significant differences in demographic characteristics between the groups. As expected, there were significant differences in BDI scores ($t = -14.60$, $p < 0.01$) and medication use ($\chi^2 = 15.43$, $p < 0.01$) between the depressed and non-depressed group. There were also significant between-group differences in the means of the diary measures unpleasantness ($t = -4.10$, $p < 0.01$), uncontrollability ($t = -2.87$, $p < 0.01$), unpredictability ($t = -2.76$, $p < 0.01$) and NA ($t = -7.46$, $p < 0.01$). Bivariate correlations between all variables (the stress dimensions and NA) were displayed in the supplementary material (Table S3).

3.2. The influence of prior NA on dimensions of daily life stress

Prior NA($t-1$) had a significant effect on unpleasantness ($b = 0.12$, $p = 0.02$), uncontrollability ($b = 0.15$, $p < 0.01$) and unpredictability ($b = 0.09$, $p = 0.06$).

3.3. The influence of daily life stress on NA: testing individual predictors

Unpleasantness, uncontrollability and unpredictability significantly predicted NA (Table 2). Random effects of the stress dimensions were all significant, indicating individual differences in negative affective reactivity.

3.4. The influence of daily life stress on NA: the unique contributions of the predictors

The three-way interaction between unpleasantness, uncontrollability and unpredictability in the prediction of NA was non-significant ($p = 0.75$). After removal of the three-way interaction, there was a significant two-way interaction between the stress dimensions unpleasantness and uncontrollability ($b = 0.01$, $p = 0.01$). The two-way interactions between unpleasantness and unpredictability ($p = 0.62$) and between unpredictability and uncontrollability ($p = 0.56$) were non-significant. They were removed to obtain the final model (Table 3).

Table 2
Results of univariable multilevel analyses of the relationship between stress dimensions and NA, controlled for prior NA.

	Estimates (Bootstrapped 95% CI)	p
Fixed effects		
Unpleasantness	0.14 (0.11–0.17)	<0.01
NAt − 1	0.23 (0.20–0.26)	<0.01
Uncontrollability	0.08 (0.05–0.11)	<0.01
NA − 1	0.24 (0.19–0.29)	<0.01
Unpredictability	0.07 (0.04–0.09)	<0.01
NAt − 1	0.25 (0.20–0.30)	<0.01
Random effects		
Unpleasantness	0.01 (0.01–0.02)	<0.01
NAt − 1	0.02 (0.01–0.03)	<0.01
Uncontrollability	0.01 (0.00–0.01)	<0.01
NAt − 1	0.02 (0.01–0.04)	<0.01
Unpredictability	0.01 (0.00–0.01)	<0.01
NAt − 1	0.02 (0.02–0.04)	<0.01

Note: CI = confidence interval.
Estimates are unstandardized B values.
The fixed and random effects of the dummy variables for morning and afternoon and a random intercept were included in the model, yet are not shown in the table as they were not variables of interest.

In Fig. 1, the significant interaction between unpleasantness and uncontrollability is visualized. At higher levels of uncontrollability of an event, individuals showed a larger increase in negative affectivity to an increase in unpleasantness. In contrast, at lower levels of uncontrollability, individuals showed a less pronounced increase in negative affectivity after an increase in unpleasantness.

The AIC and the BIC of the final multivariable model, as presented in Table 3, were lower (respectively 6511 and 6619) than the AIC and the BIC of the univariable model with the strongest individual predictor unpleasantness (respectively 6560 and 6629), indicating a better fit for the multivariable model. Unpleasantness remained the strongest predictor in the multivariable model.

Table 3
Main effects and significant interaction effect of multivariable multilevel analysis of the relationship between stress dimensions and NA, controlled for prior NA.

	Estimates (Bootstrapped 95% CI)	*p*
Fixed effects		
Unpleasantness	0.12 (0.09–0.15)	< 0.01
Uncontrollability	0.02 (0.00–0.04)	0.06
Unpredictability[a]	0.02 (0.00–0.03)	0.02
Unpleasantness*Uncontrollability	0.01 (0.00–0.02)	0.02
NAt − 1	0.23 (0.18–0.27)	< 0.01
Random effects		
Unpleasantness	0.01 (0.01–0.02)	0.01
Uncontrollability	0.00 (0.00–0.01)	0.28
Unpredictability[a]	0.00 (0.00–0.01)	0.95
Unpleasantness*Uncontrollability	0.00 (0.00–0.00)	0.65
NAt − 1	0.02 (0.02–0.04)	< 0.01

Note: CI = confidence interval.
Estimates are unstandardized B values.
The fixed and random effects of the dummy variables for morning and afternoon and a random intercept were included in the model, yet are not shown in the table as they were not variables of interest.
[a] For comparability with previous IDL studies a sensitivity-analysis was performed in which outcome expectancy and onset expectancy were separated (see Table S2). Based on the AIC and BIC values no model was strongly preferred over the other, suggesting that the presented parsimonious model did not result in an underestimation of the effects of predictability.

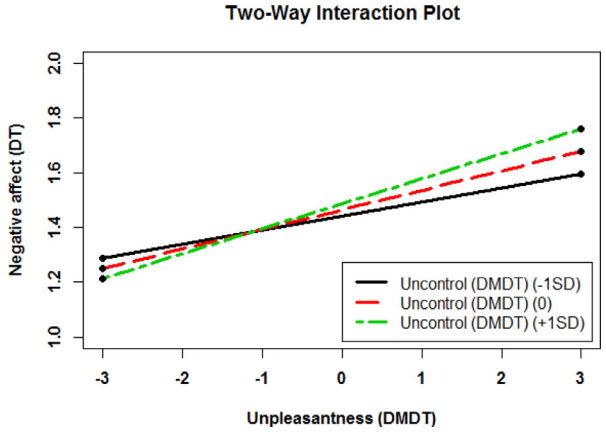

Fig. 1. Visualization of the interaction between the stress dimensions unpleasantness and uncontrollability.

3.5. The final multivariable model: interaction with depression status

To assess whether negative affective reactivity differed between depressed and non-depressed groups, interactions between the identified dimensions and group were examined. Here, the three-way interaction between depression status, uncontrollability and unpleasantness was non-significant ($b = 0.00$, $p = 0.69$). After removal of the three-way interaction, results revealed a significant two-way interaction between depression status and unpleasantness ($b = 0.09$, $p < 0.01$), and non-significant two-way interactions between depression status and uncontrollability ($b = 0.00$, $p = 0.97$) and depression status and unpredictability ($b = 0.02$, $p = 0.12$).

Table 4
Results of multivariable multilevel analyses of the relationship between stress dimensions and NA, separately for the depressed and non-depressed group.

	Depressed **Estimates (Bootstrapped 95% CI)**	***p***	*Non-depressed* **Estimated (Bootstrapped 95% CI)**	***p***
Fixed effects				
Unpleasantness	0.17 (0.12–0.22)	< 0.01	0.07 (0.05–0.10)	< 0.01
Uncontrollability	0.02 (0.00–0.05)	0.28	0.02 (0.00–0.04)	0.06
Unpredictability	0.03 (0.00–0.06)	0.03	0.01 (0.00–0.02)	0.35
Unpleasantness* Uncontrollability	0.01 (0.00–0.03)	0.09	0.02 (0.00–0.04)	0.10
NAt − 1	0.24 (0.18–0.30)	< 0.01	0.19 (0.11–0.26)	< 0.01
Random effects				
Unpleasantness	0.01 (0.01–0.03)	0.001	0.00 (0.00–0.01)	< 0.01
Uncontrollability	0.00 (0.00 – 0.01)	0.17	0.00 (0.00–0.00)	0.71
Unpredictability	0.00 (0.00–0.01)	0.95	0.00 (0.00–0.00)	0.95
Unpleasantness* Uncontrollability	0.00 (0.00–0.00)	0.94	0.00 (0.00–0.00)	0.02
NAt − 1	0.01 (0.01–0.04)	0.02	0.02 (0.02–0.05)	< 0.01

Note: CI = confidence interval, NA = negative affect.
Estimates are unstandardized B values.
The fixed and random effects of the dummy variables for morning and afternoon and a random intercept were included in the model, yet are not shown in the table as they were not variables of interest.

To further interpret the significant interaction, analyses were conducted stratified for group. In Table 4, the multivariable model is presented separately for the depressed and the non-depressed group. The depressed group showed larger increases in negative affect after unpleasant events than the non-depressed group. In Fig. 2, the interaction effect is visualized as well. It can be seen that depressed individuals have on average higher levels of negative affect than non-depressed individuals do, and that this difference increases when the unpleasantness of the event increases.

Unpleasantness as a marker of stressor intensity may share explanatory power with the more specific dimensions unpredictability and uncontrollability. For completeness, the interactions between the individual dimensions and group were also examined with models for each dimension separately. Now, unpleasantness ($p < 0.01$), uncontrollability ($p = 0.05$), and unpredictability ($p = 0.04$) all

Fig. 2. Visualization of the interaction between the stress dimension unpleasantness and participant group (depressed or non-depressed).

interacted positively with depression status (results in Table S1).

4. Discussion

The aim of the present study was to investigate whether and how stress dimensions derived from an evidence-based conceptual model predict negative affective reactivity in depressed and non-depressed individuals, in their daily lives. The three stress dimensions of interest; unpleasantness, uncontrollability and unpredictability all uniquely contributed in predicting NA. The response in NA to the combination of stress dimensions was larger in the depressed than the non-depressed group, indicating increased negative affective reactivity. This was mostly accounted for by an increased NA response to unpleasantness, a dimension that has been linked to stressor intensity. While the multidimensional stress concept of Koolhaas et al. (2011) was previously validated in animal and human experiments, we found in this ILD study that the hypothesized stress dimensions of interest predicted negative affect in daily life. This gives evidence for the usefulness of this conceptualization in a daily life setting. It is important to note that most of the measured stressors were mild in nature. It would be interesting to investigate to what extent the findings generalize to more severe stressors.

4.1. Multidimensional stress concept

In the multidimensional model, unpleasantness was the strongest predictor of negative affective reactivity, although addition of uncontrollability and unpredictability may give an even more complete image of daily life stress. This finding is in line with our hypothesis. Koolhaas et al. (2011) have postulated that unpleasantness is a quantitative dimension that is related to stressor intensity, whereas uncontrollability and unpredictability are more qualitative dimensions of stress (Koolhaas et al., 2011). Correspondingly, van Eck et al. (1998) reported twice as large an estimate for unpleasantness compared to uncontrollability. In three other studies (Peeters et al., 2003; Schneiders et al., 2006; van Winkel et al., 2015), unpleasantness was not the strongest predictor. This may be explained by the inclusion of a general measure of “event stressfulness”, which can be considered an umbrella term that captures several dimensions of stressfulness, including unpleasantness, unpredictability and uncontrollability.

Previous ILD studies investigating negative affective reactivity in depressed and non-depressed individuals used a wide variety of stress dimensions. The only previous study which included an uncontrollability dimension was consistent with our findings in reporting a significant association with NA (van Eck et al., 1998). Whereas two previous studies reported that unpredictability of an event was not a significant predictor of NA (Schneiders et al., 2006; van Eck et al., 1998), our results did show a significant effect. The dimension unpredictability was operationalized by combining two aspects, namely whether an event happened unexpectedly (onset expectancy) and whether an event went as expected (outcome expectancy). This decision was based on theoretical work suggesting that the two features are different aspects of the broader concept unpredictability (Eriksen et al., 2005; Koolhaas et al., 2011). A sensitivity-analysis in which the two aspects were separated (following the identified optimal model) showed smaller estimates for the separated variables than for the combined variable, and only onset expectancy remained a significant predictor of NA (see Table S2). Based on the AIC and BIC values no model was strongly preferred over the other, suggesting that the presented parsimonious model did not result in an underestimation of the effects of predictability. Of note, the weights of the individual stress dimensions were smaller in multivariable compared to univariable models. Seemingly, the stress dimensions to a degree have shared explanatory value, next to their unique contributions to negative affective reactivity.

To our knowledge, the present study was the first ILD study on negative affective reactivity to explore interaction effects between stress dimensions. The multidimensional model which predicted NA best included an interaction between unpleasantness and uncontrollability. This result supports the idea that controllability of unpleasant events may buffer against negative affective responses in daily life. Although this interaction has not been explicitly investigated in previous ILD studies, our findings are in line with macro-level findings. In general, control over an aversive stimulus helps to reduce stress reactions (Lefcourt, 1983). More specifically, it has been shown that individuals who experienced more perceived control, were less likely to develop depressive symptoms following stressors (Dulin et al., 2013). This knowledge may be beneficial for individuals from the general population who are sensitive to stress. In addition, this can have practical implications in clinical or professional settings. Providing individuals with a certain form of (perceived) control can reduce their stress levels, even though the stressor intensity remains consistent.

4.2. Depression

As hypothesized, using the multidimensional conceptualization of stress, the depressed group showed increased negative affective reactivity compared to the non-depressed group. Increased negative affective reactivity in depression was also reported by van Winkel et al. (2015), who investigated the occurrence of negative events, Wichers et al. (2009), who investigated unpleasantness solely and Myin-Germeys et al. (2003b), who operationalized daily life stress in a different way, namely activity stress and social stress. One previous study found blunted affective reactivity to negative events in a depressed group of participants compared to a non-depressed group (Peeters et al., 2003). However, in that study, participants were first asked whether they experienced a negative event since the last beep. Only if they answered ‘yes’ to this question they were asked to describe the event further. This may have caused a bias, as non-depressed participants reported less negative events than depressed participants, but on average these events were appraised as more stressful. Increased negative affective reactivity in the depressed group was reported for the events that were appraised as stressful. Contrary to our findings, a meta-analysis of laboratory studies revealed blunted emotional responses to both positive and negative stimuli (Bylsma et al., 2008) in depressed individuals. This pattern has been referred to as emotion context insensitivity (Rottenberg et al., 2005). A divergence between naturalistic studies and laboratory experiments has been frequently noted in other mental disorders (e.g., emotion in schizophrenia; Myin-Germeys et al., 2000). It has been suggested that this discrepancy can be explained by the differences in stimuli. Affective reactivity in laboratory experiments is mainly induced with the use of pictures or emotional imagery. These stimuli may be mildly stressful and often lack personal relevance (Grillon et al., 2013). Participants actual daily life events are personally relevant and may be more stressful resulting in increased affective reactivity. Taken together, our findings and those of previous ILD studies support the idea that negative affective reactivity to daily life stress is increased in depression.

The two groups primarily differed in reactivity to the unpleasantness dimension. The unpredictability dimension significantly predicted NA in depressed participants, but not in non-depressed participants. Considering that the interaction between group and unpredictability did not reach significance, it remains to be determined whether this observed group difference is truly meaningful. However, this finding is in line with the theory of intolerance of uncertainty, which refers to heightened negative affect in response to an uncertain situation, often associated with anxiety disorders but also with affective disorders such as depression (Shihata et al., 2016). With regard to the uncontrollability dimension, the depressed and non-depressed group did not differ in negative affective reactivity. Another ILD study did not find differences in reactivity to experienced control either (Bylsma et al., 2011). This was somewhat surprising as these findings go against the theory of

learned helplessness in depressed individuals, which refers to the structural absence of perceived control over the outcome of a situation (Seligman, 1972). One possible explanation for the null findings is that there is relatively little distinction in unpleasantness, uncontrollability and unpredictability of events encountered in daily life. If this is the case, shared variance will be partitioned to the largest predictor (i.e. unpleasantness) in statistical models. In post-hoc analyses, when interactions were tested separately for each dimension, depressed individuals indeed displayed increased negative affect responses to uncontrollable and unpredictable events as well (see Table S1). This suggests that the unpleasant events associated with enhanced negative affective reactivity in depression in the present study, were to some extent also characterized by low predictability and low controllability. As stress experience relies on subjective appraisals of events, learning to use reappraisal strategies in a therapeutic setting might be beneficial in reducing negative affect in depressed individuals in daily life.

4.3. Prior NA

Prior NA prospectively predicted higher levels of unpleasantness, uncontrollability and unpredictability, to a relatively similar extent. Consistent with theory (Lazarus and Folkman, 1984), this suggests that ongoing NA biases stress appraisal. Most ILD studies investigating affective reactivity do not report taking negative affect prior to stressful events explicitly into account (Peeters et al., 2003; Schneiders et al., 2006; Wichers et al., 2007), or control for autocorrelation in the error term only (DeLongis et al., 1988; Johnson et al., 2008; Lazarus and Folkman, 1984; van Eck et al., 1998). Here, we intentionally highlighted the strong autocorrelation in negative affect, and explicitly addressed potential confounding due to biased appraisal by including prior NA as a covariate in the analyses.

4.4. Strengths and limitations

The present study was characterized by several strengths. This study was the first to systematically investigate negative affective reactivity in relation to the combination of the key stress dimensions unpleasantness, uncontrollability and unpredictability (Koolhaas et al., 2011). Future studies are recommended to include this combination of dimensions. Secondly, to our knowledge, this is the first study to explicitly reveal the influence of prior negative affect ($NAt-1$) on subsequent self-reported event stressfulness. Evidently, it is advisable to control for prior NA to adjust for this negative bias in appraisals where appropriate. Further, whereas other ILD studies investigating stressful events and negative affect used between 30 (Bylsma et al., 2011) and 60 data points per individual (van Winkel et al., 2015), the present study included 90 data points. This means that power to detect within-individual associations was even larger than in previous studies. Lastly, the participant retention rate in the present study was relatively high and the remaining participants had only 6.9 (7.7%) missing values for the diary measures.

However, the study also had several limitations. Although we used a large absolute number of measurements, we collected three measurements per day whereas previous ILD studies used nine (Schneiders et al., 2006) or ten measurements per day (Bylsma et al., 2011; van Winkel et al., 2015; Wichers et al., 2009). There was a time lag of up to 6 h between the occurrence of a stressful event and subsequent affect measurements, and consequently we might have missed negative affective reactivity to some extent in our assessment. However, the results still demonstrate a robust detection of reactivity using this specific time lag. A higher sampling frequency might alternatively dilute the effects of stressful events by including more events of relatively minor importance.

Participants were asked to appraise the most important event since the previous beep. A weakness of this method may be the underlying assumption that whatever participants considered as most important event was the most stressful event as well, which might not necessarily apply to all stressful events. In addition, assessment of event stressfulness and NA at the same time point precludes conclusions regarding the directionality of effects, or causal relationships.

The study sample consisted for >70% of females, thus the results are more representative for women than for men. However, depression is more prevalent in women, and our male: female ratio is largely representative for the patient population.

The analysis included events across the full scale of the (un)pleasantness dimension, meaning that also pleasant events were included. Without these events, the total number of events per participants would be more than halved, greatly reducing power. However, because the inclusion of pleasant events might also blur the results, we performed a post-hoc test with only neutral and negative events for the optimal combination of measures, as well as its interaction with group status. The results were highly similar to the original analysis, and we believe that minor differences can be mostly attributed to loss of power (see also Tables S4 and S5).

5. Conclusion

Our findings provide empirical support for a multidimensional conceptualization of stress (Koolhaas et al., 2011), confirming the relevance of uncontrollability, unpredictability and unpleasantness for negative affective reactivity in a daily life setting. We found that even for mild stressful events in daily life, more perceived control can help to cope with negative stressful events. This knowledge may be beneficial for individuals from the general population who are sensitive to daily life stress. In addition, this can have practical implications in clinical or professional settings. Providing individuals with a certain form of (perceived) control can substantially reduce their stress levels, even when the stressor intensity remains consistent. In addition, the findings confirm the importance of cognitive appraisals of stress for heightened negative affective reactivity in depression, with a particular emphasis on appraisals regarding unpleasantness of events. A multidimensional conceptualization of stress is recommended, because it can be beneficial for establishing a fine-grained picture of the alterations in affective reactivity in depressed individuals.

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Author contributions

SHB, EHB, and PdJ conceived and designed the study. SHB and EHB performed the study. ECDvdS, SHB, NAG, EHB and MCW designed a data analysis plan. ECDvdS, SHB, NAG and EHB analyzed the data. ECDvdS, SHB, NAG, EHB, MCW and PdJ wrote the paper.

Competing interests

The authors declare no conflicts of interest in relation to this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2019.03.040.

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