The Automaticity of Depressive Rumination

A Test of the Habitual Nature of Ruminative Thinking in Clinical and Non-clinical Samples. Insights From an Ecological Momentary Assessment Perspective

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Thesis for the degree of Philosophiae Doctor

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Rannsóknir á vanabundnu eðli þunglyndisþanka í úrtökum háskólanema og fólks með endurtekið þunglyndi. Innsýn úr snjallsímamælingum

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Abstract

Background: Major depression is the most common psychiatric disorder, associated with the highest disease burden worldwide when it comes to years lost to disability. Efforts to identify indicators of depression risk have strongly implicated depressive rumination, a negative thinking style characterized by repetitive and passive thoughts about the causes, meanings, and consequences of one's feelings and distress. An increasingly popular theoretical perspective posits that over time depressive rumination becomes a mental habit that is initiated automatically without conscious awareness or intent in response to downward shifts in mood, making it persistent and difficult to control. However, the rumination as-a-habit account has rarely been directly tested and it is still unknown whether depression vulnerability is characterized by elevated levels of mood-reactive habitual rumination at the level of short-term dynamics.

Aims: The aim of the current research project was to address gaps in the current knowledge on depression vulnerability by utilizing a combination of experimental and novel mobile *in-the-moment* assessment strategies to better understand the dynamic interplay between mood and ruminative thinking and its habitual characteristics. Three studies were designed to test specific hypotheses involving: a) effects that fluctuations in mood have on subsequent ruminative thinking, b) the degree to which habitual characteristics of negative thinking predict such mood-reactive rumination, and c) whether mood-reactive rumination varies according to the depression-risk spectrum in line with theoretical accounts of depression vulnerability.

Methods: In study 1, a total of 115 university students completed self-report measures and participated in an experimental rumination-induction task and outcome-devaluation task measuring habit vs. goal-directed behaviour control. In study 2, a total of 97 participants recorded affect and rumination ten times daily over six days using Ecological Momentary Assessment, after completing measures of trait ruminative brooding and habitual characteristics of negative thinking (e.g., automaticity, lack of conscious awareness, intent, and control). In study 3, formerly depressed individuals with a recurrent history of depression (n = 94) and non-clinical controls (n = 55) recorded *in-the-moment* affect and rumination ten times daily over six days, after completing baseline measures of trait ruminative brooding, habitual characteristics of negative thinking, and early-life stress.

Results: In study 1, greater habitual characteristics of negative thinking were associated with ruminative brooding but not ruminative reflection, and predicted more persistent dysphoric mood following rumination-induction. Rumination was not, however, consistently associated with an imbalance in habit vs. goal-directed behaviour control. In study 2, momentary fluctuations in negative (increased) and positive (decreased) affect was prospectively associated with greater rumination at the next sampling occasion. The degree to which affect triggered a subsequent ruminative response was moderated by habitual characteristics of negative thinking in a theoretically consistent way. Stronger temporal pairing of negative affect and rumination was also associated with greater emotional inertia but less carry-over of rumination from one moment to the next. In study 3, momentary fluctuations in negative affect were prospectively associated with greater rumination at the next sampling occasion in formerly depressed participants whereas this pattern of mood-reactive rumination was not observed in healthy never-depressed participants. In formerly depressed participants, habitual characteristics of negative thinking were associated with greater mood-reactivity of rumination, particularly among those with a history of early-life stress. Mood-reactive rumination was not, however, associated with depression course nor trait ruminative brooding.

Conclusions: The findings of the studies demonstrate that fluctuations in affect can trigger ruminative thinking as a function of habit consistent with recent theoretical frameworks of depression vulnerability. Mood-reactive rumination may be a potential vulnerability marker for depression, with rumination being habitually triggered in response to momentary fluctuations in negative affect with a high degree of automaticity, and with a deleterious effect on mood. The current thesis suggests ways depression vulnerability may emerge as a dynamic relationship between negative affect and rumination across time, not captured by traditional trait measures of rumination frequency. Ecological momentary assessment may be a valuable measurement paradigm to test predictions derived from habit-accounts of depressive rumination, that have rarely been investigated until now, and might provide new insights into research on depression risk.

Keywords: Major depression, depression risk, rumination, habit, ecological momentary assessment, early-life stress,

Ágrip

Bakgrunnur: Þunglyndi (*major depression*) er algengasta geðröskunin og í dag talin vera helsta orsökin fyrir örorku á heimsvísu. Rannsóknir hafa borið kennsl á þunglyndisþanka (*rumination*) sem stóran áhættuþátt fyrir upphaf og endurkomu þunglyndis. Þunglyndisþankar eru flokkur neikvæðra hugsana sem fela í sér að dvelja lengi og endurtekið í hugsanlegri merkingu, orsök og afleiðingum eigin tilfinninga og viðbragða. Nýlegar kenningar um þunglyndi gera ráð fyrir að þunglyndisþankar séu hugrænn vani sem virkjast sjálfkrafa, án ætlunar eða vitundar, sem viðbragð við versnandi líðan. Þess vegna sé erfitt að að stjórna þessum hugsunarhætti. Rannsóknir eiga þó enn eftir að sýna fram á að vanlíðan geti kveikt á þunglyndisþönkum með slíkum hætti og að sambandið þar á milli sé vanabundið.

Markmið: Meginmarkmið rannsóknarverkefnisins var að beita tilraunaverkefnum og nýstárlegri snjallsímamælingu (*ecological momentary assessment*) til að fanga samspil líðanar og þunglyndisþanka í daglegu lífi fólks. Auk þess var reynt að meta að hvaða marki þetta samspil er bundið vana. Þrjár rannsóknir voru gerðar til að meta tilgátur um a) áhrif stundar-sveiflna (*momentary fluctuations)* í neikvæðri líðan á þunglyndisþanka, b) vanabundna eiginleika á samspil líðanar og þunglyndisþanka og c) hvort aukin tilhneiging til þunglyndisþanka í kjölfar vanlíðanar tengist frekari áhættu á þunglyndi.

Aðferð: Í rannsókn eitt tóku 115 háskólanemar þátt og svöruðu þeir sjálfsmatskvörðum um þunglyndisþanka og einkenni þunglyndis. Auk þess tóku þeir þátt í tilraunaverkefni sem ýfir upp þunglyndisþanka (*mood-induction task*) og tölvuverkefni sem metur vanabundna hegðunarstjórn (*outcome-devaluation task*). Í rannsókn tvö tóku 97 þátttakendur þátt í snjallsímamælingu, þar sem þeir svöruðu spurningum um líðan og þankagang sinn 10 sinnum á dag í 6 daga ásamt því að svara sjálfsmatskvörðum um þunglyndisþanka og vanabundna eiginleika neikvæðrar hugsunar (*habitual characteristics*; t.d. sjálfvirkni, án meðvitundar eða ætlunar og erfitt að stjórna). Í rannsókn þrjú tóku 94 einstaklingar með sögu um endurtekið þunglyndi og 55 heilbrigðir einstaklingar þátt í 6 daga snjallsímamælingu. Þeir voru jafnframt beðnir um að greina frá streituvaldandi atburðum úr ævi og svara sjálfsmatskvörðum.

Niðurstöður: Niðurstöður rannsóknar 1 sýndu að vanabundnir eiginleikar neikvæðrar hugsunar tengdust óhjálplegum

þunglyndisþönkum (*ruminative brooding*) en höfðu enga fylgni við greinandi íhugun (*ruminative reflection*). Vanabundnir eiginleikar spáðu auk þess fyrir um sterkari áhrif ýfingar (*rumination induction*) á líðan. Þunglyndisþankar höfðu engin tengsl við almenna vanabundna hegðunarstjórn (*habit directed behaviour control*). Niðurstöður rannsóknar 2 sýndu að stundarsveiflur í neikvæðri (hækkaðri) og jákvæðri (lækkaðri) líðan spáðu marktækt fyrir um aukna þunglyndisþanka frá einni stund til þeirrar næstu. Sterkari pörun stundarsveiflna í líðan og þunglyndisþönkum sást hjá þeim sem greindu frá ríkari vanabundnum eiginleikum hugsunar. Sterkari tímapörun líðanar og þunglyndisþanka tengdist einnig meiri tilfinningalegri tregðu (*emotional inertia*). Niðurstöður rannsóknar 3 sýndu að líðan kveikti einungis á þunglyndisþönkum hjá þátttakendum með fyrri sögu um endurtekið þunglyndi, og þar með í aukinni áhættu, en ekki hjá heilbrigðu fólki með enga fyrri geðsögu. Hjá þátttakendum með fyrri sögu um þunglyndi spáðu vanabundir eiginleikar hugsunar fyrir um hversu mikið stundarsveiflur í líðan kveikti á þunglyndisþönkum yfir tíma, og var sérstaklega áberandi hjá þeim sem höfðu sögu um streituvaldandi atburði í æsku. Tímapörun líðanar og þunglyndisþanka var hins vegar alveg óháð þunglyndissögu þátttakenda (fjölda lota, aldur við upphaf, leifareinkenni). Sjálfsmatskvarði um tíðni þunglyndisþanka spáði ekki fyrir um tímapörunina.

Ályktanir: Niðurstöður rannsóknanna sýna að sveiflur í líðan geta kveikt á þunglyndisþönkum og að áhrifin séu mest áberandi hjá þeim hafa sterka vanabundna eiginleika hugsunar. Þessar niðurstöður eru í samræmi við kenningar fræðimanna um þunglyndisþanka sem hugrænan vana. Niðurstöðurnar gefa til kynna að sterkari vanabundin tímapörun á milli líðanar og þunglyndisþanka geti verið næmisþáttur fyrir þunglyndi. Sveiflur í líðan geti kveikt á þunglyndisþönkum með mikilli sjálfvirkni og tilheyrandi versnun í líðan. Þær gefa auk þess til kynna að hefðbundnir sjálfsmatskvarðar á tíðni þunglyndisþanka nái ekki utan um samspil líðanar og þunglyndisþanka og því þurfi rannsóknir að leggja ríkari áherslu á aðra eiginleika vanabundinnar hugsunar í rannsóknum á áhættuþáttum þunglyndis. Í framtíðinni gætu snjallsímamælingar reynst vel til að prófa tilgátur um vanabundið eðli þunglyndisþanka, sem hingað til hefur tekist illa að leggja prófstein vísindanna á.

Lykilorð: Þunglyndi, næmi fyrir þunglyndi, vani, snjallsímamæling, streituvaldandi atburðir í æsku

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Contents

List of abbreviations

ANCOVA = Analysis of Covariance
BAI = Beck Anxiety Inventory
BDI = Beck Depression Inventory-II
CBM = Cognitive Bias Modification
CBT = Cognitive Behavioural Therapy
COHS = Creature of Habit Scale
CTES = The Childhood Traumatic Events Scale
DSEM = Dynamic Structural Equation Modelling
DSI = Devaluation Sensitivity Index
EMA = Ecological Momentary Assessment
FFG = The Fabulous Fruit Game
HINT = Habit Index of Negative Thinking
MBCT = Mindfulness Based Cognitive Therapy
MINI = MINI-International Neuropsychiatric Interview
MRSI-A = Momentary Ruminative Self-Focus Inventory
MSSD = Mean Squared Successive Differences
NA = Momentary Negative Affect
PA = Momentary Positive Affect
PANAS = Positive and Negative Affect Schedule
PTSD = Post-Traumatic Stress Disorder
RFD = Recurrent Formerly Depressed Individuals
RRS = The Ruminative Responses Scale
RUM = Momentary Rumination
SRHI = Self-Report Habit Index
VAR = Variable
VAS = Visual Analogue Scale
VIF = Variance Inflation Factor

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Paper I

Hjartarson, K. H., Snorrason, I., Friðriksdóttir, Á., Þórsdóttir, B. B., Arnarsdóttir, N. B., & Ólafsson, R. P. (2020). An experimental test of the habit-goal framework: Depressive rumination is associated with heightened habitual characteristics of negative thinking but not habit-directed behavior control. *Journal of Experimental Psychopathology*, *11*(4), https://doi.org/10.1177/2043808720977168.

Paper II

Hjartarson, K. H., Snorrason, I., Bringmann, L. F., Ögmundsson, B. E., & Ólafsson, R. P. (2021). Do daily mood fluctuations activate ruminative thoughts as a mental habit? Results from an ecological momentary assessment study. *Behaviour Research and Therapy*, *140*, 103832. https://doi.org/10.1016/j.brat.2021.103832.

Paper III

Hjartarson, K. H., Snorrason, I., Bringmann, L. F., & Ólafsson, R. P. (2021). Automaticity and depression: Daily mood-reactive rumination in People with and without depression history. Accepted for publication in Journal of Psychopathology and Clinical Science (previously Journal of Abnormal Psychology). https://doi.org/10.1037/abn0000752.

Declaration of contribution

Paper 1

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Paper 3

Design & conceptualization: Kristján Helgi Hjartarson, Ragnar P. Ólafsson, Ívar Snorrason. *Data collection*: Kristján Helgi Hjartarson. *Coding of EMA app*: Kristján Helgi Hjartarson and Bjarni E. Ögmundsson. *Statistical Analyses*: Kristján Helgi Hjartarson & Laura F. Bringmann. Paper was written by Kristján Helgi Hjartarson under the supervision of Ragnar P. Ólafsson, Ívar Snorrason and Laura F. Bringmann.

1 Introduction

Major depression is the most common psychiatric disorder, associated with the highest disease burden worldwide when it comes to years lost to disability (World Health Organization, 2017). With a lifetime prevalence of around 15% (Bromet et al., 2011), a high risk of recurrence - as high as 80% in some studies (Mueller et al., 1999), and risk increasing with number of episodes (Lewinsohn et al., 2000), it is one of the largest threats to health in the world, imposing challenges on health care providers to advance its treatment and researchers to better understand its causes.

Repetitively thinking about one's current problems or distress is thought to be an indistinguishable part of normal life. We all tend to focus on our concerns from time to time and such analyses often reveal potential answers to our concerns and actions taken toward solving them. However, excessive rumination about one's problems that does not lead to tangible solutions or actions has been found to contribute to feelings of despair and is considered a hallmark characteristic of major depressive disorder.

Efforts to identify indicators of depression risk have strongly implicated ruminative thinking in both the initial onset, maintenance, and recurrence of major depressive disorder (Wisco & Nolen-Hoeksema, 2008). Despite increased interest and research on the subject over the past three decades, important theoretical assumptions regarding the nature of rumination still remain untested, impeding advancements in theoretical models of depression risk and, ultimately, its prevention.

Depressive rumination is the subject of the present thesis. Many contemporary theories on rumination conceptualize it as a mental habit that is initiated automatically without conscious awareness or intent in response to downward shifts in mood, making it difficult to control. A widely held notion that has never been directly tested. The current thesis aimed to test that assumption. Theoretical models of rumination as-a-habit are discussed. The thesis presents results of a series of studies that were conducted using both experimental and ecological momentary assessment methodology in attempt to better understand the role of habit in the dynamic interplay between affect and ruminative thinking.

1.1 Depressive Rumination: Definition and Evidence as a Vulnerability Factor to Depression

Research has identified cognitive vulnerability factors for depression onset and maintenance at the level of biases in attention, memory, and interpretation (e.g., Joormann & Arditte, 2014). Depressive rumination is a repetitive, persistent, and recurrent way of thinking about one's negative emotions, problems, and personal concerns (Watkins, 2008). It has been conceptualized as a negative thinking style that involves repetitively and passively dwelling on the causes, meanings, and consequences of one's feelings and distress (Nolen-Hoeksema & Morrow, 1993). Rumination has been found to contribute to depression vulnerability by shaping and influencing people's information processing.

Evidence suggests that rumination exacerbates negative affect and cognition, acting like an emotional magnifier (Nolen-Hoeksema et al, 2008) and has been found to result in more negative thoughts about the past, present and the future (Lyubomirsky et al., 1998). This in turn leads to more negative mood, creating a vicious cycle of mutual amplification between negative thinking and negative mood, wherein each increases the likelihood of the other (Watkins & Roberts, 2020). Furthermore, although often perceived by the person as a way to gain insights and a better understanding of one's current problems, rumination has been found to impair problem solving by making individuals view their problems as more overwhelming, view them in more abstract rather than specific terms, and less likely to implement any solutions that they come up with (Nolen-Hoeksema et al, 2008). Finally, rumination has been found to reduce people's motivation and interfere with active approach behaviours, such as engaging in pleasant activities (Lyubomirsky & Nolen-Hoeksema, 1993) and has been associated with increased avoidance behaviours (Bishop et al., 2018).

Ample evidence supports rumination as a vulnerability marker for the development and maintenance of depressive symptoms and episodes (Nolen-Hoeksema et al., 2008; Watkins, 2008). Prospective longitudinal studies using the Ruminative Responses Scale (RRS; Nolen-Hoeksema & Morrow, 1991) have found that people who tend to ruminate are more likely to develop depressive disorders and experience more persistent periods of dysphoric mood than low ruminating individuals (Just & Alloy, 1997; Nolen-Hoeksema, 2000; Spasojevic & Alloy, 2001). A ruminative disposition has also been found to be related to a greater number of depressive episodes

(Ciesla & Roberts, 2002) highlighting its role as a vulnerability factor in recurrent depression.

Depression appears to be specifically characterized by high levels of ruminative brooding (Joorman et al., 2006), a subtype of rumination that involves passively focusing on symptoms of one's distress and the possible meaning and implications of those symptoms (Treynor et al., 2003). In contrast, ruminative reflection, which consists of active cognitive problem solving that may improve one's mood, has traditionally been thought less associated with depression (e.g., Burkwell & Shirk, 2007). Brooding is thought to involve a more self-critical, evaluative, and judgmental type of self-focus that leads to a greater persistence of negative mood (Rude et al., 2007).

The most widely used self-report measures to assess depressive rumination is without doubt the Ruminative Responses Scale (Nolen-Hoeksema et al., 1999). The RRS yields two five-item subscales of ruminative brooding and reflection, respectively. Studies using the RRS have provided ample support for the distinction between the two subcomponents of rumination. For example, Joormann et al. (2006) found that brooding, but not reflection, was associated with depression related cognitive biases such as an attentional bias towards sad faces. Burkwell and Shirk (2007) found that brooding, but not reflection, was associated with maladaptive coping styles whereas reflection was associated more adaptive coping strategies. They also found that only brooding, but not reflection, prospectively predicted symptoms of depression in adolescents. In the same vein, brooding, but not reflection, has been found to mediate the relationship between emotional abuse in childhood and depressive symptoms in adulthood (Raes & Hermans, 2008), between self-criticism and suicidal thoughts in adults (O'Connor & Noyce, 2008), between stress and depressive symptoms (Cox et al., 2012), and between negative cognitive styles and symptoms of depression in college students and depressed patients (Lo et al., 2008). However, ruminative reflection is elevated in both currently and formerly depressed samples (Joormann & Gotlib, 2010) which suggest that adaptive self-reflection may turn into maladaptive brooding, when individuals attempting to understand their problems repeatedly, fail to come up with solutions (Takano, Sakamoto, & Tanno, 2011; see also results of Miranda & Nolen-Hoeksema, 2009 for evidence that ruminative reflection might have some detrimental effects).

Another cardinal measure of rumination, experimental rumination-induction (Nolen-Hoeksema & Morrow, 1993), has also demonstrated the detrimental effect that ruminative brooding has on mood and cognition. In this experimental paradigm, participants focus on the meaning, consequences and causes of their current (or induced) negative affect when reading a number pre-made emotionally neutral prompts (Nolen-Hoeksema and Morrow, 1993). Studies using the rumination-induction task have found that rumination leads to decreased problem solving and heightened and prolonged negative affect and cognition in dysphoric (Nolen-Hoeksema & Morrow, 1993) and clinically depressed individuals *but not in non-depressed participants* (Donaldson & Lam, 2004; Lavender & Watkins, 2004).

For example, Donaldson and Lam (2004) found that depressed participants experienced a deterioration in their mood and gave poorer solutions on a step-by-step problem-solving task following rumination-induction. In comparison, rumination-induction did not have an impact on mood or problem-solving in non-depressive participants. Rimes & Watkins (2005) found that rumination-induction increased ratings of negative self-judgements (e.g., self as worthless and incompetent) in depressed participants but not in non-depressed participants. Also, Lavender & Watkins (2004) found that depressed individuals demonstrated increased hopelessness following rumination-induction whereas it had no effect on mood and future thinking in a non-depressed comparison group.

However, rumination-induction has also been found to results in a greater persistence of negative mood in non-depressed participants w*hen first induced into a negative mood state* (Burkhouse et al., 2017; Ciesla & Roberts, 2007; Joormann & Siemer, 2004). For example, Ciesla & Roberts (2007) utilized a standard rumination-induction task wherein college students were first induced into a negative mood state prior to ruminating. They found that following mood-induction rumination led to a greater persistence of negative mood whereas a control distraction task did not. But why does rumination demonstrate such a mood-dependent effect?

1.2 Rumination as a Mood-Reactive Mental Habit

An increasingly popular theoretical perspective suggests that depressive rumination is a mental habit that is initiated automatically without conscious awareness or intent in response to downward shifts in mood, making it persistent and difficult to control (Farb et al., 2015; Watkins & Nolen-Hoeksema, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). The principal theory of depressive rumination, the Responses Styles Theory (Nolen-Hoeksema, 1991), put forth more than three decades ago, defined rumination as an enduring and stable *habitual-like* cognitive response to changes in mood (Nolen-Hoeksema & Morrow, 1991). Consistent with this, rumination has often been described as habitual in the depression literature (see e.g., Hertel, 2004) and recent theoretical models of depression vulnerability still evoke the idea of rumination as-a-habit in order to explain its persistent and recurrent nature (e.g., Farb et al., 2015; Koster et al., 2011). This perspective suggests that negative mood, of the kind that anyone might experience, is toxic for habitual ruminators, thus making them vulnerable to depression. This conceptualisation of rumination as a habit therefore differs from traditional theories of rumination as a stable *trait* or *tendency* (Nolen-Hoeksema & Morrow, 1993) in that they view rumination as a more fluctuating and *state* dependent phenomena that is not only dependent on depressed mood but also on dynamic within-day shifts in negative mood.

Habits are behaviours that occur frequently and unintentionally (Orbell & Verplanken, 2010). They are formed by learned associations between behavioural responses and their performance contexts. Once formed, context cues become automatic triggers for the behaviour, such that it is controlled solely by the presence of the context cue (Wood & Neal, 2007) and are thus characterized by a high degree of automaticity (e.g., lack of conscious awareness, deliberate intent, mental efficiency, and lack of control; Verplanken et al., 2007). In other words, repeating a reinforced behaviour in a stable environmental context leads to stimulus-response associations in memory, that may lead to the automatic triggering of the behaviour within the specific environmental context. Thus, allowing the individual to perform routine behaviours with a high degree of efficiency and low demand on attentional resources. Once formed and strengthened over time, the original incentive for those habitual behaviours may become increasingly irrelevant but the environmental context is still able to trigger the habitual behaviour (Dickinson, 1985; Wood & Neal, 2007) and override the individual's intentions (Gardner et al., 2020). Such automatic cuing of habitual behavioural

responses has been implicated in different forms of psychopathology, including eating disorders, addiction, and obsessive-compulsive disorder (e.g., Gillan, 2014; Horstmann et al., 2015; Sjoerds et al., 2013).

According to habit accounts of rumination, transient episodes of ruminative thinking are thought to arise in response to perceived discrepancies between desired states and present perceived states. This process is considered adaptive when rumination facilitates progress towards desired states, however, when goals are repeatedly not reached, rumination persists and mood deteriorates (Martin & Tesser, 1996; Watkins, 2008). The consistent use of passive, negative and abstract ruminative thoughts to cope with such persisting discrepancies cause NA and ruminative thinking to be paired over time, turning rumination into a habit triggered by context (i.e., negative affect) rather than goals (Watkins & Nolen-Hoeksema, 2014). According to habit accounts, brooding leads to the recurrent pairing of negative mood with ruminative thoughts which develops into a mood-driven habit over time, whereas reflection is not assumed to play such a role (Watkins & Nolen-Hoeksema, 2014).

This raises the question under what conditions such transient episodes of rumination turn into a maladaptive habit of thought. It has been hypothesised that person-specific factors that contribute to a lack of flexible responding (i.e., restricted coping repertoire, cognitive inflexibility) and situational factors that systematically thwart important goals (i.e., chronic stress and abuse) may serve as potential risk factors for transient episodes of rumination to consolidate into a habitual style of thinking (Shaw et al., 2019; Watkins & Roberts, 2020).

Consistent with this, meta-analyses have identified early-life stress not only as a risk factor for the development of depression but also for an earlier age of onset and more chronic course of illness (Nanni et al., 2012; Nelson et al., 2017). Notably, stressful early-life events, particularly a history of physical, sexual, and emotional abuse, predict elevated levels of rumination in adulthood (Heleniak et al, 2016; LeMoult et al., 2020; Young et al., 2012) and rumination in turn has been found to mediate the relationship between childhood abuse and depression severity later in life (Kim et al., 2017; McLaughlin & Hatzenbuehler, 2009; Paredes & Calvete, 2014). Such stressful and abusive environments may constrain peoples' emotional coping repertoire, leading to greater passivity and reduced cognitive flexibility, increasing the likelihood of ruminative thinking. At the same time, stressful

and abusive environments may thwart the resolution of personally important goals leading to up-regulated negative affect. Under such circumstances, rumination might consolidate as a mental habit when consistently paired with negative mood over time (Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020).

Furthermore, it is possible that a general propensity for habit formation in everyday life may contribute to depression (Byrne et al., 2021). Using the Creature of Habit Scale, a measure of individual differences in everyday habitual responding, Ersche et al. (2017) found that experiences of adversity during childhood – a well-known risk factor for depression (Nelson et al., 2017), was associated with increased automatic habitual responding in everyday life. Furthermore, Heller and colleagues (2018) found that on a two-stage decision-making task, individuals high in depression demonstrated greater habitual and less goal-directed decision making in the face of stress. Finally, a study by Ólafsson et al. (2020) found that on an outcome-devaluation task, a stronger dependence on habit relative to goal-directed behaviour control was associated with a greater number of previous depressive episodes in a group of formerly depressed individuals. In this experimental paradigm, previously trained responses that resulted in valued outcomes (i.e., were reinforced), lose their value as the outcome becomes devalued. Repeating previously reinforced but currently devalued responses (i.e., slips-of-action) can be taken as a persistence of previous goal-directed behaviour that has become habitual, and insensitive to outcome value (de Wit, 2017; Linnebank et al., 2018). Thus, there is some preliminary evidence that depression may be associated with difficulties modulating behaviours in service of goals, making people more prone to habitual responding, and might thus predispose people to develop rumination as a habit.

1.3 Initial Evidence for Rumination as a Habit

Is there any evidence to support the widely held notion that rumination is a mood-reactive habit? Using the brooding subscale of the Response Style Questionnaire (RRS; Nolen-Hoeksema, 1991; Treynor et al., 2003), often considered a measure of habitual rumination, numerous studies have found elevated levels of brooding in currently and remitted depressed individuals compared to non-clinical controls (reviewed in Aldao et al., 2010). However, the RRS only assesses the frequency of rumination in response to low mood (rated on a scale of repetition from “almost never” to “almost always; Treynor et al., 2003) and does not assess other key characteristics of habits as

automatically triggered behavioural responses (e.g., are initiated without awareness, unintended, and difficult to control; Watkins & Roberts, 2020).

Few studies have directly tested the notion of rumination as a mental habit. In a systematic review of the literature on mental habits (Colvin et al., 2021) not a single study was found that directly tested the notion of rumination as a habit (including search terms such as “mental habits”, “automatic thinking”, and “rumination”). However, there exists some preliminary evidence for the rumination as-a-habit account. In a novel simulation study, Van Vugt et al. (2018) showed that modelling rumination as-a-habit best predicted the impairments of depressed participants on a sustained attention task. Moreover, Verplanken et al. (2007) found that rumination was strongly associated with self-reported lack of conscious awareness, lack of deliberate intent, and difficulties in controlling negative thinking. They used the Habit Index of Negative Thinking (HINT) - a self-report measure of the habitual characteristics of negative thoughts (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness). They also found that when controlling for negative cognitive content, habitual characteristics of negative thoughts predicted low self-esteem, decreased positivity bias in self-relevant stimuli, and predicted symptoms of depression at 9 months follow up. Furthermore, Watkins and Baracaia (2001) found that self-identified ruminators report that rumination tended to occur without conscious intent and was difficult to control. More recently, Ólafsson et al. (2020) found that habitual characteristics of self-focused thoughts were elevated in formerly depressed individuals, compared individuals with no depression history. Ruminative brooding was found to be associated with increased habitual characteristics, whereas this relationship was not evident for ruminative reflection, often considered a more adaptive form of rumination.

Although promising, these findings are limited in several ways. First, rumination was measured at the trait level, at a single time-point and averaged across time, and may therefore not apply to state fluctuations in affect and rumination. Secondly, rumination was assessed via self-report, by asking respondents to think back to a time when they felt sad, increasing the probability of retrospective bias. Finally, previous studies did not address the hypothesized temporal context-response association between affect and rumination, rendering causal inference impossible. Thus, they were unable to test the critical assumption that the mood-reactivity of rumination is a function of habit.

1.4 Capturing Rumination at the Level of Short-Term Dynamics - Rumination Induction and Ecological Momentary Assessment

One way to address limitations of previous studies is to utilize a standard rumination-induction procedure wherein participants are first induced into a negative mood state – a validated paradigm designed to assess depressive rumination in an experimental setting. In this experimental task, participants are asked to focus on the meaning, consequences and causes of their current (or induced) negative affect when reading a number pre-made emotionally neutral prompts (Nolen-Hoeksema and Morrow, 1993). Experimental studies using the rumination-induction procedure have found that rumination leads to heightened and prolonged negative affect and cognition in both dysphoric (Nolen-Hoeksema & Morrow, 1991) and clinically depressed individuals (Donaldson & Lam, 2004; Lavender & Watkins, 2004). Rumination-induction also results in greater persistence of negative mood in non-dysphoric participants when first induced into a negative mood state (e.g., Burkhouse et al., 2017; Ciesla & Roberts, 2007; Joorman & Siemer, 2004). Thus, it might allow for the measurement of the possible influence that habitual thinking (e.g., as assessed using the HINT) has on mood-induced rumination.

Another way to address the shortcomings of previous studies is to use more ecologically valid assessment procedures, such as Ecological Momentary Assessment (EMA), to capture the interplay between affect and rumination in the flow of daily life experiences. The advantage of EMA is that it provides a way of studying individuals' and their responses in real life settings, yielding data with high ecological validity (Myin-Germeys, 2018). In EMA, individuals are asked in their normal daily life to report on their experiences, thoughts, feelings, and symptoms in response to a signal provided at either pre-determined or random unpredictable moments, or in response to events of interests, and are usually sampled multiple times a day. EMA has been used to study various topics including social interaction, physical activity, cognitive functioning, and psychological states and mental disorders (Csikszentmihalyi & Larson, 2014). A variety of open-ended questions, Likert scales, geo-location, and real-time monitoring of activity and biological phenomena have been used (Bos et al., 2015; Myin-Germeys et al., 2009). Traditionally, such data on "in the moment" experiences was gathered with paper-and-pencil in combination with beepers that signalled a response. However, advances in web-bsed solutions and software provide

the opportunity to conduct such experience sampling through smartphones, which have become ubiquitous with everyday life.

Traditional assessment:
”In the past 2 weeks, I was…”

Provides a single total score for each individual. Scores represents the individual in general. The focus is on traits and *tendencies.* Relies on accurate self-recall.

Ecological Momentary Assessment:
”Right now, I am...”

Captures many instances of the same variable/s and their interaction over time within each individual. Focus is on states and *in-the-moment experiences*. Provides data with high ecological validity but can be more cumbersome.

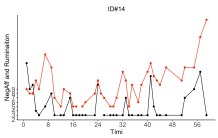

Figure 1. The difference between traditional self-report that captures *traits* and ecological momentary assessment (EMA) that focuses on capturing meaningful fluctuations and trends of *states* in the flow of daily life experiences.

Whereas traditional self-report measures capture tendencies to think or behave in a certain way *in general* (i.e., traits) or over long periods (e.g., past month), the assessment target of EMA are *in-the-moment* experiences (i.e., states) which are presumed to fluctuate and/or change over time in some meaningful way (Schmitt & Blum, 2020). The difference between traditional measures of self-report and EMA assessment are visualized in Figure 1. Traditional self-report measures of rumination, for example, provide a single total score, or subscale scores, which represent the degree to which an individual ruminaties in general. However, that trait score might not accurately predict the degree to which the individual ruminates at a particular specific moment in time (i.e., state rumination) nor predict the changes that occur in ruminative thinking over the course of the day (fluctuations and trends in state rumination).

An increasingly popular perspective suggests that major depression, rather than being a static condition, constitutes a dynamic system representing the continuous interaction of moment-to-moment emotions, thoughts, and behaviours (Wichers, 2014). This perspective fits well with the dynamic relationship between affect and rumination posited in habit accounts of rumination. The longitudinal nature of EMA makes it ideally suited to examine temporal relationships between context and behaviour on the microlevel (Myin-Germeys, 2018) and provides a way to test dynamic models empirically that has been missing so far. Furthermore, critical to the measurement of habits, EMA can evaluate fluctuations in affect and rumination over short temporal intervals, allowing researchers to investigate contingencies of which people may be unaware (Neal & Wood, 2009).

Research using EMA have consistently found that individuals with major depression experience lower mean levels of daily positive affect (PA) and higher mean levels of negative affect (NA; Aan het Rot et al., 2012). A meta-analysis found that depressive symptoms may be associated with increased instability (i.e., the magnitude of fluctuations) and inertia (i.e., the persistence or resistance to change) of moment-to-moment PA and NA (Houben et al., 2015). Such affect dynamics may reflect early warning signs that precede the onset of depression (Wichers, 2014) highlighting their potential utility in predicting treatment response (Husen et al., 2016) and enhancing the personalization of psychotherapy (Fisher & Boswell, 2016).

Studies using EMA in student samples have revealed a reciprocal relationship between affect and rumination at the level of short-term dynamics, with rumination predicting subsequent changes in NA, and NA predicting changes in rumination to the same effect (Blanke et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008). They have also found that a strong temporal relationship between NA and subsequent rumination is associated with greater symptoms of depression and a greater tendency for negative mood to linger from moment-to-moment (i.e., emotional inertia; Brose et al., 2015; see also Kuppens, Allen, & Sheeber, 2010).

There exist no EMA studies that directly tests the assumption that fluctuations in NA trigger rumination across time as a function of habit. Most importantly, existing research has yet to determine if individuals at increased risk of depression demonstrate elevated levels of mood-reactive rumination in daily life and whether they do so as a function of habit. If habit-like triggering of daily mood-reactive rumination predisposes people to the onset of

depression episodes, it should be observed in at-risk samples in a euthymic state and be unconfounded with current symptoms (e.g., Ingram et al., 2011). Furthermore, the relationship of such mood-reactive rumination with other known mood dynamics, such as emotional inertia, remains to be investigated.

1.5 Outline of the Studies, Research Aims and Hypotheses

Many recent theoretical formulations of depressive vulnerability conceptualize rumination as a mood-reactive habit. This fits well with the phenomenology and clinical descriptions of rumination as a recurrent, hard to control and automatic cognitive process. However, the notion of rumination as a mental habit has rarely been directly tested. This is perhaps due to the general availability of self-report measures, sophisticated methodology needed to measure rumination as-a-habit, and the face validity and long tradition of such habit accounts of rumination in clinical psychology. The current research project aimed to extend the scope of previous studies on rumination and test the assumption of rumination as a habit using a combination of both established and novel methodological approaches. A series of studies were conducted that aimed to a) establish whether maladaptive rumination brooding is associated with heightened habitual characteristics; b) test whether rumination is a mood-reactive phenomena; and c) if so whether the mood-reactivity is a function of habitual thinking; d) to determine whether individuals at increased risk of depression demonstrate elevated levels of such mood-reactive rumination in daily life

The thesis describes findings reported in three research papers. These papers include one experiment and two ecological momentary assessment studies into the role of habitual thinking in the dynamic interplay between affect and rumination. These studies were conducted in samples of students with a range of depressive symptoms as well as in euthymic participants with a history of recurrent major depression. A group of healthy non-clinical adults without a history of major depression was also recruited to serve as a comparison. This approach of using both student and clinical samples is in line with vulnerability-stress models of depression (Abramson et al., 2002; Ingram & Luxton, 2005) and recent emphases on dimensional approaches to the study of mechanisms contributing to psychopathology (Kozak & Cuthbert, 2016) and provides a clinical comparison between two groups thought to lie at opposite extremes of the depression vulnerability dimension (Ingram et al., 2011). The specific aims and hypothesis of each study are described in detail below. The methodology and results of each

study are provided in the chapters that follow. The thesis concludes with a conceptual discussion of the main findings and their implications for the study of ruminative thinking in major depression.

1.5.1 Aims and Hypotheses - Study 1

The aim of study 1 was to experimentally investigate the notion of rumination as a habit using a combination of self-report and experimental measures in a sample of students with varying levels of depression symptomology. Although there exists preliminary evidence for the notion of rumination as a mental habit (Ólafsson et al., 2020; Verplanken et al., 2007; Vugt et al., 2018; Watkins and Baracaia, 2001), the existent findings do not address some of the key assumptions of the habit account. Little research is available on whether depressive brooding, but not ruminative reflection, is associated with habitual attributes and, importantly, it remains to be directly tested whether heightened habitual characteristics are associated with greater detrimental effects of rumination. In the present study we investigate this using a combination of both self-report measures and experimental tasks.

First, it was expected that greater self-reported habitual characteristics of negative thinking (i.e., repetition, lack of conscious awareness and intent, mental efficiency, lack of control and self-descriptiveness) would be associated with increased ruminative brooding but not ruminative reflection measured with the RRS.

Second, to expand on this, we also utilized a rumination-induction task to assess brooding-like rumination in an experimental setting. Rumination that has become habitual, should be associated with greater aversive consequences. It was therefore expected that habitual characteristics of negative thinking would predict a greater persistence of NA and cognition following induction of ruminative brooding.

Finally, depression may be associated with a general propensity for habit formation in everyday life (Byrne et al., 2021; Heller et al., 2018; Ólafsson et al., 2020). We therefore also explored to what extent ruminative brooding may be related to more general difficulties in modulating behaviours in service of goals, that can make people more prone to forming habits. We explored if rumination, as indexed both by self-report and experimental induction, is associated with greater habitual responding on a self-report

measure of habit propensity – the Creature of Habit Scale - and on an outcome-devaluation experimental task – the Fabuluous Fruit Game. We expected rumination to be associated with greater self-reported daily-habits and greater slips-of-action on the outcome-devaluation task.

1.5.2 Aims and Hypotheses - Study 2

The main objectives in study 2 were to assess if the habitual characteristics of negative thoughts are related to the dynamic interplay between NA and ruminative thinking in the flow of daily life experiences. Participants provided everyday 'in the moment' data about their immediate experiences when prompted by alert. Momentary affect and rumination were assessed multiple times during the day over a 6-day period, allowing for the assessment of their temporal relationships. Two hypotheses were derived from the habit framework of depressive rumination (Farb et al., 2015; Watkins & Nolen-Hoeksema, 2014; Shaw et al., 2019; Watkins & Roberts, 2020).

First, it was expected that increased NA should prospectively predict greater rumination-levels at the next sampling occasion. Secondly, because the habit framework predicts that rumination can develop into a mood-linked habit (Watkins & Nolen-Hoeksema, 2014), measures of habit should be specifically associated with the degree to which NA triggers rumination across time rather than just being associated with average levels of momentary rumination. It was therefore expected that the interplay between NA and rumination would be moderated by habitual thinking, with increased habitual characteristics predicting greater rumination in response to fluctuations in NA.

In a more exploratory fashion, we tested if the same pattern of findings would be apparent when looking at the deterioration of PA as a possible trigger for momentary rumination and to what extent it was associated with a greater persistence of NA (i.e., emotional inertia).

1.5.3 Aims and Hypotheses - Study 3

The aim of study 3 was to provide a test of the presumed mood-reactive and habitual nature of depressive rumination in individuals at increased risk of depression. According to habit accounts, rumination as a vulnerability should first and foremost be mood-reactive and such mood-reactive rumination

should be more evident in those at greater risk for depression (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020).

This was done by investigating the dynamic interplay between NA and ruminative thinking in the flow of daily life experiences among euthymic participants with a history of recurrent major depression, and therefore at increased risk of future depression episodes (e.g., Buckman et al., 2018). A low depression-risk group of euthymic non-clinical controls was recruited to serve as a comparison.

First, it was expected that recurrent formerly depressed individuals would demonstrate considerable mood-reactive rumination in daily life, such that momentary increased NA would prospectively predict greater rumination-levels at the next sampling occasion. However, it was expected that mood-reactive rumination would not be apparent in more resilient healthy non-clinical controls with no depression history.

Secondly, is when rumination turns habitual that it is thought to be triggered to a greater extent in response to negative mood (Watkins & Nolen-Hoeksema, 2014). The degree of mood-reactive rumination in daily life of formerly depressed participants was therefore expected to be moderated by habit, with heightened habitual characteristics of negative thinking predicting greater rumination in response to momentary fluctuations in NA.

To our knowledge, this is the first direct empirical test of the proposed mood-reactivity of rumination in the daily life of individuals with a history of depression. We followed these hypotheses with a number of exploratory analyses. As mentioned previously, early-life stress might serve as a catalyst for habitual rumination through more systematic pairing between episodes of state ruminative thoughts and negative mood (Shaw et al., 2019; Watkins & Roberts, 2020). Furthermore, it is reasonable to expect rumination, that has consolidated as a persistent habit, to be associated with a more severe course of depression. It was therefore explored if a) early-life stress, particularly a history of physical, sexual, or emotional abuse, and b) depression course (number of episodes, age of onset and stability of remission) was associated with greater mood-reactive rumination.

2 Method

2.1 Self-Report Questionnaires

2.1.1 Measures of Psychiatric Symptom Severity

Depressive symptoms were assessed with the Beck Depression Inventory-II (BDI-II; Beck et al., 1996), a 21 item self-report questionnaire. Items are rated on a 4-point scale ranging from zero to three, with a maximum total score of 63. Higher scores indicate increased symptom severity. Anxiety symptoms were assessed with the Beck Anxiety Inventory (BAI; Beck & Steer, 1990), a self-report questionnaire that consists of 21 items that measure the severity of anxiety symptoms. Each item is rated on a 4-point scale, with a maximum score of 63. The Icelandic versions of the BDI-II (Arnarson et al., 2008) and BAI (Sæmundsson et al., 2011) have shown good psychometric properties. Both measures were used in study 1 and the BDI-II was used in study 2 and 3.

2.1.2 The Ruminative Responses Scale (RRS)

The RRS (Nolen-Hoeksema & Morrow, 1991) is a self-report measure of ruminative disposition which contains 22 items that assess a person's tendency to think about the symptoms, causes, and consequences of their depressed mood. Items are rated on a 4-point Likert scale ranging from "never or almost never" to "always or almost always". Factor analysis has found the RRS to yield two five-item subscales; the brooding subscale (RRS-B), which measures more passive, analytical and repetitive forms of thinking, and is thought to represent the maladaptive component of rumination, and a reflection subscale (RRS-R) which measures more active and adaptive forms of ruminative thinking (Treynor et al., 2003). The Icelandic version of the RRS has shown good psychometric properties (Pálsdóttir & Pálsdóttir, 2008). Both subscales were used in study 1. The RRS-B was used in studies 2 and 3.

2.1.3 Habit Index of Negative Thinking (HINT)

The habitual quality of negative thinking was measured with the HINT (Verplanken et al., 2007), a 12 item self-report scale that measures the degree to which negative thoughts occur frequently, are initiated without awareness, are unintended, are difficult to control, and are self-descriptive.

Each item is rated on a 7-point scale in response to the general prompt; "Thinking negatively about myself is something…". and included items such as "I do unintentionally" and "I start doing before I realize I'm doing it". The HINT thus taps the process aspects – the repetitive and automatic nature of the thoughts – which are considered as key elements of mental habits, and which can be distinguished from the content and valance of the thoughts themselves (Verplanken et al., 2007; Watkins, 2008). Evidence of discriminant validity between habitual negative thinking and rumination come from a series of studies by Verplanken et al. (2007) that found HINT to uniquely contribute to feelings of low self-worth over and above rumination, finding them to be related but empirically distinct. Furthermore, a commonality analyses by Gustavson et al. (2019) showed that although HINT shared variance with both rumination and worry in predicting symptoms of depression, HINT also accounted for considerable unique variance not attributable to either rumination or worry. The Icelandic version of the HINT has high internal consistency and good discriminant validity (Ólafsson et al., 2019).

2.1.4 The Creature of Habit Scale (COHS)

The COHS (Ersche et al., 2017) was used to assess individual differences in participants' proneness to habits in everyday life. The COHS is a 27-item self-report questionnaire that assesses two aspects of habitual responding, routine and automaticity, in a variety of domains. Items were rated on a 5-point scale ranging from "*strongly disagree*" to "*strongly agree*" and included items such as "*whenever I go into the kitchen, I typically look in the fridge*" and "*I often find myself running on autopilot*". The Icelandic version of the COHS has good psychometric properties (Jóhannesdóttir & Jóhannesdóttir, 2019). The COHS was used in study 1.

2.1.5 The Childhood Traumatic Events Scale (CTES)

The CTES (Pennebaker & Susman, 1988) was used in study 3 to assess participants' history of early-life stress before the age of 17. Participants were asked whether they had experienced certain stressful events, the age at which they experienced them (not reported here), how traumatic the event had been on a 7-point scale (1 = not at all traumatic, 7 = extremely traumatic). Events included: Physical abuse, mugging or assault; sexual abuse or molestation; major parental conflicts; death of a family member or

person very close to the child; severe illness or injury; and other traumatic events which were perceived to impact the individual's personality or life trajectory. An additional item to assess history of emotional abuse was added in the present study; "Prior to the age of 17, did a parent or other household member frequently swear at you, degrade, or humiliate you?" based on questions in other well-established measures of adverse childhood experiences (e.g., the ACE scale; Felitti et al., 1998). The CTES yielded a cumulative score, by summing the number of stressful early-life events, and a total severity score, calculated by summing the severity of each reported event. The CTES demonstrates good reliability and validity (Pennebaker & Susman, 1988) and sensitivity to clinical symptoms following early life stress, including PTSD and depression (Scheller-Gilkey et al., 2004).

2.2 Lifetime History of Depressive Episodes and Psychiatric Diagnoses

The MINI-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) was used to obtain psychiatric diagnoses in study 3. MINI is a semi structured interview for the most common Axis I disorder of the DSM-IV. Good interrater reliability and good convergent validity with lengthier diagnostic interviews such as the Composite International Diagnostic Interview (CIDI) have been reported for MINI (Sheehan et al., 1997). An Icelandic version of the MINI was administered for which adequate convergent validity with CIDI has been measured (Sigurðsson, 2008; see also Kristjánsdóttir et al., 2015). The present study utilized a composite version of MINI with the depression module from MINI-Plus but with other modules from the standard MINI. Based on Ólafsson et al. (2020) questions were added to assess the number of past depressive episodes, age of onset of the first depression episode, as well as the stability of current remission. After confirming the presence of a past major depressive episode with the MINI-Plus depression module, participants were asked how often they had experienced such an episode where the symptoms were present most of the day, nearly every day for at least 2 weeks and caused significant disruptions in daily life functioning during that period. Participants were asked to indicate when each episode had started and when it ended. The researcher noted precise dates of duration, when possible, or rounded to the first, fifteenth or last day of each month. Only episodes of adequate duration (2 weeks or more) and with a period of 2 months or more with no symptoms between episodes were included. Age of onset was operationalized as the age of the earliest episode identified in this way. To assess the stability of remission

participants were asked to indicate if they had experienced one or both core symptoms of depression (depressed mood/anhedonia) in the past 8 weeks, according to the DSM-IV and as assessed on the MINI, but with a shorter duration of at least one week. If endorsed, they were subsequently asked about other potential symptoms of depression with a duration of at least one week. Stability of remission was defined as the total number of subclinical depression symptoms present during the previous 8 weeks. We recorded audio from all MINI interviews. A sample of 22 recordings (approx. 20% of all formerly depressed individuals included in the clinical trial) was randomly selected for reassessment by an independent researcher. Interrater reliability between the original evaluation and reassessment was .98, 95% CI = [0.96, 0.99] for number of previous episodes and .91, 95% CI = [0.78, 0.96] for age of onset. All participants sampled were found to have a history at least 3 previous episodes but currently in remission with complete agreement between raters.

3.3 Experimental tasks

3.3.1 Experimental Measure of Ruminative Disposition

Rumination was assessed using a standard rumination-induction task (Nolen-Hoeksema & Morrow, 1993) in study 1. The task included a negative mood manipulation in order to facilitate the emergence of ruminative processing (see e.g., Burkhouse et al., 2017; Ciesla & Roberts, 2007; Joorman & Siemer, 2004).

Mood Manipulation. All participants listened to an 8-minute musical excerpt from Prokofiev's "Russia Under the Mongolian Yoke", remastered at half speed, while thinking about a sad autobiographical event from their life. This combination of music and autobiographical recall has been found to be effective in inducing a transient dysphoric mood in previous research (Jarrett et al., 2012; Lau et al., 2004; Martin, 1990).

Rumination-Induction. Participants were then instructed to engage in a ruminative cognitive task developed by Nolen-Hoeksema and Morrow (1993), which has been used extensively in prior experimental research to induce an analytical and brooding thinking style (See Nolen-Hoeksema et al., 2008; Rimes & Watkins, 2005). Participants focused on the meaning, consequences and causes of their current feelings for 8 minutes when

reading 28 prompts adapted from Nolen-Hoeksema & Morrow (1993). They were instructed to "*for the next few minutes, try your best to focus your attention on each of the ideas on the following pages. Read each item slowly and silently to yourself. As you read the items, use your imagination and concentration to think about the causes, meanings, and consequences of the items. Spend a few moments visualizing and concentrating on each item, attempting to make sense of and understand the issues raised by each item*". Items were presented on sheets of paper. The items consisted of self- and emotion-focused sentences such as "*think about the way you feel*" and "*think about the level of motivation you feel right now*".

Ratings of mood were obtained with a visual analogue scale (VAS) that was administered before and after the mood manipulation and following the rumination-induction. Each VAS consisted of a 152 mm line with arrows indicating increased strength of happy and sad moods from the middle of the scale (scale labelled "*sad*" and "*happy*" at each extreme"). Responses were scored on a scale ranging from 0 to 152 with higher scores indicating greater dysphoric mood.

In line with prior studies (Rimes & Watkins, 2005) measures of negative self-judgements were obtained to assess the impact of rumination on participants' cognition. Ratings of "*worthless*", "*unlovable*", "*acceptable*", "*competent*" (final two reversed scored), were obtained with four VAS before and after the mood manipulation and immediately following the rumination-induction. Each scale consisted of a 152 mm line (labelled "Not at all" to "Totally" at each extreme) and were scored on a scale ranging from 0 to 152, where increased scores indicated greater negative self-judgements. To ease interpretation and comparison with prior research, ratings of worthlessness and incompetency were combined to form a total score of autonomy-type judgements (i.e., achievement-based evaluations) whereas ratings of unacceptability and unlovability were combined to form a total score of sociotropy-type judgements (i.e., interpersonal evaluations; Rimes & Watkins, 2005)

3.3.2 Experimental Task of Habit vs. Goal-Directed Behaviour Control

The Fabulous Fruit Game (FFG) was used to measure participants reliance on habit over goal-directed behaviour control. The FFG is a computerized outcome-devaluation task (programmed in Visual Basic 6.0) designed to measure the extent to which instrumental performance is under the control of habitual versus goal-directed action strategies. A modified version (see Worbe et al., 2015) of the original FFG (de Wit et al., 2007; Gillan et al., 2011) was used. This experimental task infers an increased reliance on habit over goal-directed behaviour control when a previously rewarded and overlearned response to a cue (instrumental training) persists even after the reward has been devalued (i.e., slips-of-action; for a detailed summary see Worbe et al., 2015). The FFG was used in study 1. A graphic representation is provided in the supplementary materials (Appendix). All participants completed the instrumental training task followed by either the slips-of-action or baseline test (presented in a counterbalanced order).

Instrumental training. Participants were presented with a series of six boxes with pictures of fruits on them, presented one at a time at the centre of the screen. Each box had a unique fruit image on the front (e.g., bananas) and a different fruit image inside (e.g., pineapple). Participants learned two instrumental responses (left or right button-presses) to gain rewarding outcomes (earn points by collecting fruits inside boxes). The fruits inside the boxes were worth points (cumulative scores shown on the screen). Correct responses revealed the fruit outcome inside (points awarded) but incorrect responses showed an empty box (no points awarded). The fruits on the outside served as discriminative stimuli (three fruits signalled that the right response was correct, and the other three that the left response was correct). Participants were instructed to learn by trial and error which was the correct response (left vs. right) for each outcome (fruit inside) and to try to earn as many points as possible, with more points awarded for faster correct responses (from 1 to 5 points).

Slips-of-action test. This test was designed to assess the relative contribution of habitual versus goal-directed control over instrumental responses learned during the instrumental training phase. Each of the nine test blocks consisted of a 10-second screen that presented all the six different fruit outcomes (i.e., the six fruit outcomes inside the boxes) from the initial learning phase. Two of the six fruits had a red X on them, indicating

that they were now devalued and collecting them would result in subtraction of points. Following the ten-second presentation, each of the boxes was presented one at a time in quick succession, showing only the discriminative stimulus (the fruit image outside the box). Participants earned points by pressing the correct response to collect the still valuable fruit outcomes inside. However, they were instructed to refrain from responding to the boxes that contained the devalued fruit inside, since it led to subtraction of points. No feedback of correct or incorrect responses was provided during this stage (i.e., the boxes remained closed). Failure to withhold responses to stimuli linked with devalued outcomes (i.e., 'slips-of-actions') is thought to reflect an increased reliance on stimulus-response habits. In contrast, selective responses to valuable as opposed to devalued outcomes, on the basis of current outcome value, is thought to reflect goal-directed action control. Participants completed 108 trials over nine blocks with each of the six discriminative stimuli presented two times per block in random order. Each outcome was devalued three times across all blocks. Although similar to traditional cognitive inhibition tasks (e.g., go/no-go tasks), that tap the ability to override prepotent responses and inhibiting the processing of irrelevant material (i.e., inhibiting stimulus-response associations), outcome-devaluation was designed to measure the ability to alter an overtrained response based on changes in outcome contingencies (i.e., altering response-outcome associations). However, it is possible that outcome-devaluation involves some form of higher-order cognitive control processes. The outcome-devaluation task therefore includes a control test (see baseline test blow) to account for general test demands on working memory and response inhibition (de Wit, 2017).

Baseline test. This additional test was randomly performed either before or after the slips-of-action test. The baseline test was designed to control for general test demands on working memory and response inhibition of the slips-of-action test. It had an identical structure to the slips-of-action test, the only difference being that the discriminative stimuli (fruits outside the box) were devalued rather than the outcomes (fruits inside the box). Therefore, this test did not require an evaluation of the anticipated outcome of one's action as the slips-of-action test and was intended to account for individual differences in general executive control on the task, independent of sensitivity to outcome devaluation.

3.4 Ecological Momentary Assessment

3.4.1 Momentary Mood ratings

Participants rated their current mood at each alert during the EMA period. The choice of items was based on the widely used Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) and previous EMA studies (revealing items with high loadings on NA; e.g., Wichers et al., 2012). NA consisted of the following items: 1) I feel sad right now, 2) I feel irritable right now, and 3) I feel guilty right now. PA consisted of the items: 1) I feel happy or cheerful right now, 2) I feel enthusiastic right now, and 3) I feel satisfied right now. Participants responded using a five-point Likert scale from 1 (Not at all) to 5 (Very much). In study 2 NA had an α = 0.96 at the between-level and α = 0.56 at the within-level. In study 3 NA had an α = 0.97 at the between-level and α = 0.54 at the within-level.

3.4.2 Momentary Rumination

The Momentary Ruminative Self-Focus Inventory - Abbreviated (MRSI-A) is a 6-item questionnaire that measures state-level fluctuations in ruminative self-focus (Mor et al., 2013). An abbreviated form (Conolly & Alloy, 2017; Hjartarson et al., 2021) was chosen for use during the EMA period which contained three items: 1) Right now, I am thinking about how happy or sad I feel, 2) Right now, I wonder why I react the way I do, and 3) Right now, I am thinking about the possible meaning of the way I feel. Participants indicated their degree of rumination at the time of the alert using a 7-point Likert scale, from 1 (Strongly disagree) to 7 (Strongly agree). The MRSI-A has shown excellent internal consistency and is correlated with alternative measures of rumination (Connolly & Alloy, 2017) and has been found to be sensitive to changes in response to experimental manipulations of depressive rumination (e.g., Grol et al., 2015; Hertel et al., 2014). In study 2 the MRSI-A had an α = 0.98 at the between-level and α = 0.81 at the within-level. In study 3 the MRSI-A had an α = 0.98 at the between-level and α = 0.83 at the within-level. A sample notification, affect rating, and item on the MRSI-A as presented during the EMA assessment is provided in Figure 2.

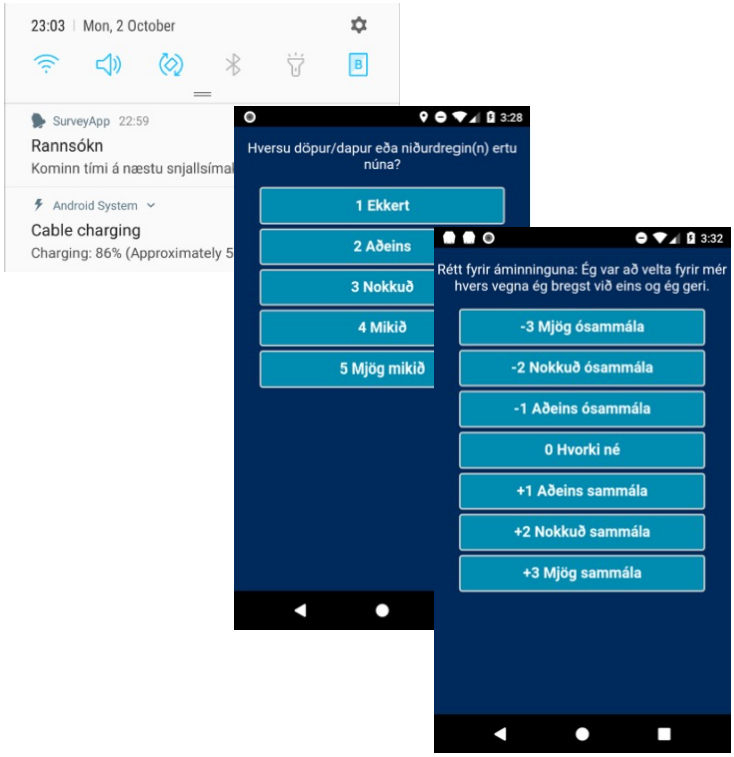

Figure 2. A sample notification, affect rating, and rumination item on the MRSI-A as presented on a mobile device during the EMA assessment.

2.5 Participants and Procedures

2.5.1 Study 1

Participants were 115 students (27 males, 88 females; mean age 23.8 years; SD = 4.4) enrolled at the University of Iceland. They were students that responded to an introductory e-mail sent out to all registered students at the university. Inclusion criteria was an age between 18-65 years and having a good command of both spoken and written Icelandic. We requested volunteers for a study on depression vulnerability although we made it clear that participants did not have to be depressed to take part. All participants

were volunteers but received a financial compensation for their participation (value: 4000 ISK, approx. $30 USD).

The study was approved by the National Bioethics Committee and reported to the Icelandic Data Protection Authority (protocol number VSN-182). The measures were administered over a single in-laboratory assessment session. Participants first answered self-report questionnaires (BDI-II, BAI, RRS, HINT, COHS) and partook in the rumination-induction task (administered in a counterbalanced order). Finally, they participated in the FFG experimental task.

2.5.2 Study 2

Drawing on the sample as in study 1, participants were subsequently invited to take part in a 6-day EMA assessment period. The study was approved by the National Bioethics Committee and reported to the Icelandic Data Protection Authority (protocol number VSN-182). Due to technical difficulties seven participants were unable to participate and three dropped out of the study due to time limitations and had no valid responses. Of the participants, 106 completed the EMA measurements. Eight were subsequently excluded due to inadequate EMA compliance (fewer than 10 completed alerts), resulting in a final sample of 97 participants (24 males, 73 females; mean age 23.3 years; SD = 2.81). Following the in-laboratory assessment session, participants were briefed one-on-one on the EMA procedure, and reviewed a sample EMA alert with the researcher to ensure proper understanding of the smartphone app and the sampling procedure. Beginning the following day after the in-lab assessment, participants were prompted by the smartphone app to answer 10 alerts per day for six consecutive days during a 12-h period (between 10 a.m. and 10 p.m.). Alerts were programmed according to a stratified semi-random interval scheme. Each day was divided into ten 72-minute intervals, with a signal occurring randomly within each interval, with an average of 92 minutes between alerts. Each time, participants gave their momentary rating of rumination and affect (PA, NA, MRSI-A). Participants were instructed to answer given how they felt and thought “in the moment” and to complete the measures immediately upon receiving an alert. After receiving an alert, participants had 15 minutes to respond before it expired. Alerts were presented and responses collected using The Experience Sampler App (Thai & Page-Gould, 2017) an open-source smartphone app intended for ecological momentary assessment research (www.experiencesampler.com). Upon completing the EMA period,

participants returned to the laboratory where they were debriefed and received compensation.

2.5.3 Study 3

In total, 103 recurrent formerly depressed individuals (RFDs) participated in the study, of which 94 (19 men, 75 women; mean age 38.8 years; SD = 10.9) provided sufficient EMA data (>20%). A total of 55 healthy non-clinical controls (NCs; 12 men, 43 women; mean age 39.7 years; SD = 11.9) were recruited, all of which provided adequate EMA responding. Data was consecutively collected as a part of a randomized controlled treatment trial of mindfulness-based cognitive therapy (for preregistration of the trial see isrctn.com: No. 92714827). The current study is based on data collected at baseline prior to therapy, including questionnaires and EMA. Ethics approval for the therapy trial and baseline comparisons was attained from the National Bioethics Committee, the Bioethics Committee of the Primary Health Care in the capital area in Iceland and reviewed by the Icelandic Data Protection Authority (protocol number VSN-235).

RFDs were recruited via referrals from general practitioners and mental health specialists in primary care centres, as well as through public advertisements, to participate in a trial on the efficacy of Mindfulness Based Cognitive Therapy (MBCT) for recurrent depression. Those interested were invited for a short telephone screening to assess their eligibility. The telephone screening consisted of target questions from the depression module of the MINI diagnostic interview (see below) to probe for current symptoms of depression and prior depression history. It also contained question regarding prior psychiatric diagnoses, use of depression medications, and recent or current psychotherapy. Potentially eligible participants were invited for a screening session where a clinical interview was administered. Inclusion criteria were (1) an age between 18 and 65 years at study entry; (2) a history of three or more major depressive episodes with, at least, two episodes within the last five years, of which one occurred within the last two years; (3) At least 2 months since the last depressive episode ended. Exclusion criteria were (1) current major depressive episode; (2) moderate or severe depression symptoms (a score >19 on the Beck Depression Inventory - II; Beck et al., 1996); (3) current or past manic or hypomanic episode; (4) current or past psychotic disorder; (5) presence of substance abuse within the last 12 months; (6) presence of active and

serious suicidal thoughts; (7) practices mediation and/or yoga on a regular basis (no more than 1 or 2 times a week, respectively); (8) unstable anti-depressive medication treatment during past eight weeks and/or changes to current treatment planned or anticipated during the next four months; (9) psychotherapy targeting depression, either currently or during the past month and/or participation in psychotherapy targeting depression scheduled during the next four months; (10) inability to complete baseline assessment (e.g. due to language or cognitive difficulties). Diagnoses were obtained with the MINI-International Neuropsychiatric Interview (MINI 5.0; Sheehan et al., 1998; Icelandic version; Kristjánsdóttir et al., 2015) by postgraduate trainees in clinical psychology adhering to the *Statistical Manual of Mental Disorders* (4th ed.; DSM-IV; APA, 2000).

NCs were simultaneously recruited through public advertisements in national newspapers, social media, leaflets, and a local website. Potential participants were screened for eligibility with a short telephone interview. Potential participants were invited for an in-laboratory visit where a clinical interview was administered. Inclusion criteria were (1) an age between 18 and 65 years at study entry; (2) a score of 19 or lower on the BDI-II. Exclusion criteria were (1) presence or history of a major depressive episode according to the DSM-IV diagnostic criteria evaluated in the MINI diagnostic interview; (2) presence or history of other mental disorders according to the MINI diagnostic interview; (3) inability to complete baseline assessment.

After inclusion in the study, participants partook in a 2 hour in-laboratory session where assessment as part of the clinical trial took place. Participants completed self-report questionnaires (BDI-II, RRS, HINT, CTES) and were briefed one-on-one on the EMA procedure by a research assistant following a standardized research protocol. The EMA items were explained by a research assistant, exemplifying the meaning of each item, and answering any questions. Participants then reviewed a sample EMA alert with the researcher to ensure proper understanding of the smartphone app and the sampling procedure. Beginning the following day after the in-lab assessment, participants were prompted by the smartphone app to answer 10 alerts per day for six consecutive days following the same EMA procedure used in study 2, with the exception that participants now had 25 minutes to respond before the alert expired. Upon completing the EMA period, participants returned to the laboratory where they were debriefed and received compensation for their participation (the equivalent of €30).

2.6 Statistical Analyses

2.6.1 Study 1

A priori power analyses using G*power (Faul et al., 2007) indicated that a sample of 110 participants would yield 0.9 power to detect small regression effect sizes (f = 0.15) with 4 predictor variables and medium bivariate correlations (p = 0.3). We therefore aimed for recruiting a sample of 110 to 120 participants. The IBM SPSS 24 Statistics package was used to calculate Pearson's correlation, hierarchical linear regressions, and mixed ANCOVA with Greenhouse-Geisser correction if assumption of sphericity was violated. To assess multicollinearity in the regression analyses we looked at the Variance Inflation Factor (VIF) which did not indicate problems due to multicollinearity in any of the analyses (VIF values ranged between 1.000 and 1.720). All statistical tests were two-sided (alpha level = 0.05) with confidence intervals of 95%. Effect sizes were estimated using Cohen's *d,* partial eta-squared (partial η^2), and change in R^2. For discriminative performance on the FFG, a Devaluation Sensitivity Index (DSI; see also Snorrason et al., 2016) was computed for the slips-of-action test and baseline test. The DSI was constructed by subtracting the percentage of responses to cues linked to devalued outcome from the percentage of responses to cues linked to valued outcomes. Thus, lower DSI values on the slips-of-action test reflected less sensitivity to devaluation (i.e., habitual responding).

2.6.2 Study 2

Descriptive statistics were computed using R (R Core Team, 2018) using the packages *ggplot2* for data visualization (Wickham, 2009) and *MplusAutomation* for reading Mplus output into R (Hallquist & Wiley, 2018). Participants with fewer than 10 out of 60 completed EMA alerts were excluded from the analyses. Previous research has shown that measures with less than 30% completed alerts may be less reliable (Delespaul, 1995). Our results remained virtually unchanged when using a more conservative criteria of at least 20 out of 60 valid alerts. We therefore present results based on the more inclusive sample in our analyses. Given the nested structure of the data (repeated assessments within individuals) we utilized Dynamic Structural Equation Modelling (DSEM) in Mplus 8.1, a multilevel approach to analysing EMA data (Hamaker et al., 2018; Muthén & Muthén, 2017). Using DSEM we fitted cross-lagged models to investigate the dynamic

relationship between momentary affect and rumination. The models were run using Bayesian estimation with non-informative priors. We used 50.000 iterations on two independent Monte Carlo Markov Chains, of which every 10th was recorded for estimation purposes. A Bayesian approach is used in DSEM because it allows for the simultaneous estimation of multiple outcome variables and their covariances, whereas separate models for each outcome would have been required using a frequentist approach. Furthermore, it allows for the modelling of time-series data when the interval between measurements is of unequal distance (Schuurman et al., 2016) which is typically ignored in multilevel approaches using maximum likelihood estimation, which can lead to biased parameter estimation (Ryan et al., 2018). We provide standardized results for within-person and between-person effects. All continuous between-level variables were grand-mean centered. In our models, statistical significance is based on the credible interval not containing zero (the default in DSEM). The corresponding Mplus code is provided below.

DSEM Mplus syntax in Study 2

TITLE: DSEM multilevel cross-lagged model for momentary rumination and affect with HINT as a between level predictor

Note: Variable 'Affect' was either negative (NA) or positive (PA) affect

```
Data:
        File is Data.dat;
Variable:
        NAMES =
        ID
        Affect (NA/PA)
        Rumination
        Habit Index of Negative Thinking (HINT);


        CLUSTER = ID; !specifies the person ID
        USEVAR = Affect Rumination HINT;
        BETWEEN = HINT;  !specifies the between-level predictor
        LAGGED = Affect(1) Rumination(1); ! lags affect and
        rumination by 1
        MISSING = ALL (9999);

DEFINE:  CENTER HINT (GRANDMEAN); !Center HINT so that
        intercepts give the mean of
        the parameters
```

Analysis:

TWOLEVEL RANDOM;
ESTIMATOR = BAYES; **!use Bayesian estimator**
PROCESSORS = 2;
BITERATIONS = (50000); **!number of minimum iterations is 50.000**
THIN = 10; **!use estimate from every 10th iteration**
POINT = MEAN;

MODEL:

%WITHIN% **!random slopes for the autoregressive (ar) and cross-lagged paths (cl)**
ar1| Affect ON Affect&1; **!autoregressive path for affect**
ar2 | Rumination ON Rumination&1; **!autoregressive path for rumination**
cl1 | Affect ON Rumination&1; **!cross-lagged path predicting affect**
cl2 | Rumination ON Affect&1; **!cross-lagged path predicting rumination**

%BETWEEN%
ar1 ar2 cl1 cl2 Affect Rumination on HINT; **!specify between-level predictor HINT**
ar1 ar2 cl1 cl2 Affect Rumination WITH
ar1 ar2 cl1 cl2 Affect Rumination; **!allow for correlated error terms.**

OUTPUT:

TECH1 TECH4(CLUSTER) TECH8 STDYX; **!within-person standardized output**

To test our hypotheses, two successive multilevel models were computed, with either NA or PA as a measure of momentary affect. A visual representation of the models is presented in Figure 3.

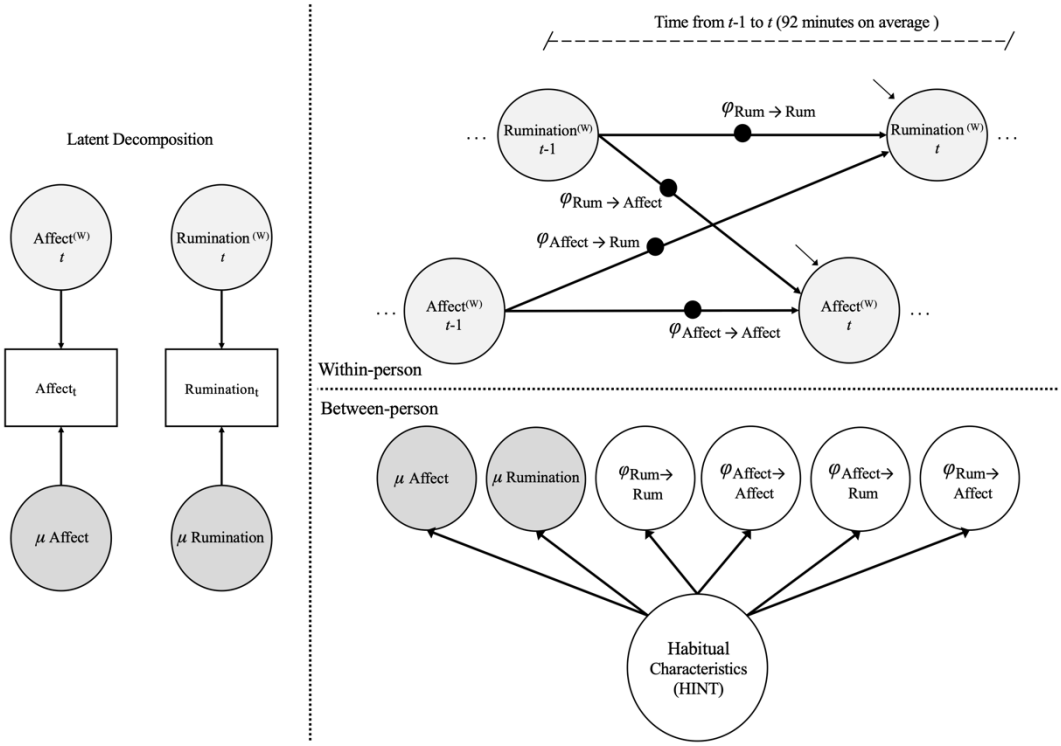

Figure 3. Multilevel cross-lagged model estimating the effect of habitual characteristics of negative thinking (HINT) on the temporal association between momentary affect (NA/PA) and rumination (MRSI-A) in study 2. Black dots indicate random effects. (w) represent within-person estimates.

In both models, rumination (MRSI-A) and affect (NA/PA) at any given time-point (*t*) were predicted by rumination and affect at the previous time-point (*t-1*). We were interested in the effect of the variables on themselves (autoregressive paths) and on each other (cross-lagged paths). These associations were allowed to differ between individuals (i.e., random means and slopes). We tested whether habitual characteristics (HINT) predicted the strength of the person-specific autoregressive and cross-lagged relationships

between rumination and affect. We follow Hamaker and colleagues (2017a, 2017b, 2018) in presenting our models. The models decompose affect and rumination into latent within- and between-person components. The within-person components describe affect and rumination of individual *i* at time *t*:

$$Affect_{it} = \mu_{Affect,\,i} + \varphi_{1i}\, Affect^{(w)}_{it\text{-}1} + \varphi_{3i}\, Rumination^{(w)}_{it\text{-}1} + \zeta_{1it}$$

$$Rumination_{it} = \mu_{Rumination,\,i} + \varphi_{2i}\, Rumination^{(w)}_{it\text{-}1} + \varphi_{4i}\, Affect^{(w)}_{it\text{-}1} + \zeta_{2it} \qquad \text{(eq. 1)}$$

where $\mu_{Affect,\,i}$ and $\mu_{Rumination,\,i}$ are the time-invariant (between-person) means of affect and rumination for individual *i.* The autoregressive parameters φ_{1i} and φ_{2i} represent the effect of the variables at *t-1* on themselves at time *t.* The cross lagged parameters φ_{3i} and φ_{4i} are the effects of the variables at *t-1* on each other at time *t*. The parameters ζ_{1it} and ζ_{2it} represent the residual variation at time-point *t* not explained by rumination and affect at the previous time-point *t*-1. Both the means μ_i and the lagged parameters φ_i are allowed to vary across individuals (hence the subscript *i*). Scores were latent person-mean centered to better capture fluctuations in NA and rumination relative to individuals' mean levels suring the assessment period (the default in DSEM; Asparouhov et al., 2018). We estimate the effect on HINT on these random effects on the between-level:

$$\begin{aligned}
\mu_{Affect,\,i} &= \gamma_{00} + \gamma_{01}\,\mathrm{HINT}_i + u_{0i} \\
\mu_{Rumination,\,i} &= \gamma_{10} + \gamma_{11}\,\mathrm{HINT}_i + u_{1i} \\
\varphi_{1i} &= \gamma_{20} + \gamma_{21}\,\mathrm{HINT}_i + u_{2i} \\
\varphi_{2i} &= \gamma_{30} + \gamma_{31}\,\mathrm{HINT}_i + u_{3i} \\
\varphi_{3i} &= \gamma_{40} + \gamma_{41}\,\mathrm{HINT}_i + u_{4i} \\
\varphi_{4i} &= \gamma_{50} + \gamma_{51}\,\mathrm{HINT}_i + u_{5i}
\end{aligned} \qquad \text{(eq. 2)}$$

where $\gamma_{00\text{-}50}$ is the fixed or group average of the parameters and u_j is the individual deviations from these effects (see eq. 2). On the between level, HINT, denoted as γHINT, is included as a predictor of the person-specific means and person-specific autoregressive and cross-lagged associations. All the parameters were allowed to covary with each other. We report within-person standardized coefficients. In the models, statistical significance is based on the credible interval not containing zero (the default in DSEM).

2.6.2 Study 3

Analyses were conducted in Mplus version 8.5 (Muthén & Muthén, 2017) and in R version 4.0.3 (R Core Team, 2020), using the packages *ggplot2* for data visualization (Wickham, 2009), *MplusAutomation* for reading Mplus output into R (Hallquist & Wiley, 2018). The package *psych* in R was also used to calculate individual mean squared successive differences (MSSDs), which provide the average magnitude of each person's moment-to-moment fluctuations in NA and rumination (Revelle, 2020). Analyses of MSSD moment-to-moment fluctuations were the only analyses not conducted using multilevel DSEM since scores were calculated per person. Participants with fewer than 12 out of 60 (20%) completed alerts were excluded from the analyses. Previous research has shown that EMA assessment with less than 30% completed alerts may be unreliable (Delespaul, 1995). The same pattern of findings was observed when using a more conservative criteria of at least 20 out of 60 valid alerts. Like in Study 2 we therefore present results based on a more inclusive sample of in our analyses.

To test our hypothesis that momentary fluctuations in NA predict subsequent rumination in RFDs but not NCs, three successive models were computed using DSEM. Again the models were run using Bayesian estimation with uninformative priors using 50.000 Markov Chain Monte Carlo iterations, of which every 10th was recorded for estimation purposes. A visual representation of the models is shown in Figure 4. The corresponding Mplus code is provided below.

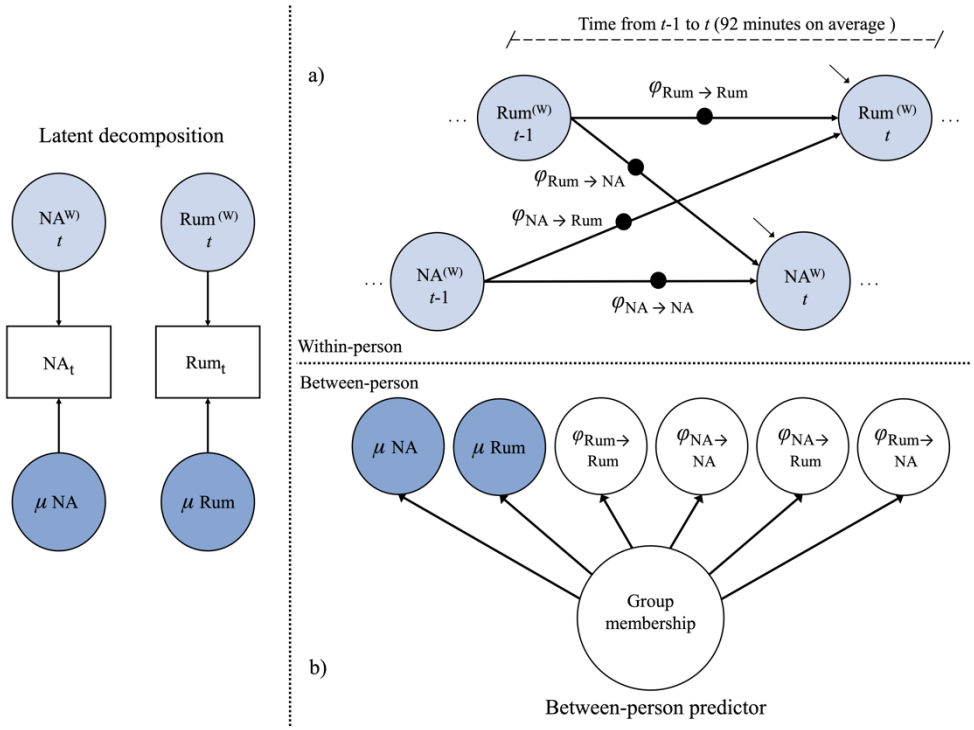

Figure 4. Multilevel cross-lagged model estimating the effect of group membership on the temporal associations between momentary negative affect (NA) and rumination (RUM) in study 3. Black dots indicate random effects. (w) represent within-person estimates.

DSEM Mplus syntax in Study 3

TITLE: DSEM multilevel cross-lagged model for momentary rumination and affect with group membership (formerly depressed/non-clinical controls) as a between-level predictor.

```
Data:
        File is Data.dat;
Variable:
        NAMES =
```

```
        ID
        Negative affect (NA)
        Rumination
        Group;

        CLUSTER = ID; !specifies the person ID
        USEVAR = Affect Rumination Group; !specifies which variables to use
        BETWEEN = Group; !specifies the between-level predictor.
        LAGGED = Affect(1) Rumination(1); !lags affect and rumination by 1
        MISSING = ALL (9999);

Analysis:
        TWOLEVEL RANDOM;
        ESTIMATOR = BAYES; !use Bayesian estimator
        PROCESSORS = 6;
        BITERATIONS = (50000); !number of minimum iterations is 50.000
        THIN = 10; !use estimate from every 10th iteration
        POINT = MEAN;

MODEL:
        %WITHIN% !random slopes for the autoregressive (ar) and cross-lagged paths (cl)
        ar1| NA ON NA&1; !autoregressive path for NA
        ar2 | Rumination  ON Rumination&1; !autoregressive path for rumination
        cl1 | NA ON Rumination&1; !cross-lagged path predicting NA
        cl2 | Rumination ON NA&1; !cross-lagged path predicting rumination

        %BETWEEN%
        ar1 ar2 cl1 cl2 NA Rumination on Group; !estimate the effect of Group
        ar1 ar2 cl1 cl2 NA Rumination  WITH
        ar1 ar2 cl1 cl2 NA Rumination; !allow for correlated residual terms.


OUTPUT:
        TECH1 TECH4(CLUSTER) TECH8 STDYX; !within-person standardized output
```

Note: When analysing moderation effects both primary effects and their interaction term on were included on the between-person level. Example shows the moderating effect of HINT on cumulative early-life stress:

%BETWEEN%
ar1 ar2 cl1 cl2 NA Rumination on HINT C_stress HINTxC_stress; **!estimate the effect of HINT, cumulative stress and their interaction.**
ar1 ar2 cl1 cl2 NA Rumination WITH
ar1 ar2 cl1 cl2 NA Rumination; **!allow for correlated residual terms.**

We first modelled the within-person relationships between momentary NA and rumination (see eq. 1) for each group separately to estimate significant paths within each group (see Figure 4a). Negative affect and rumination (MRSI-A) at any given time-point (*t*) were predicted by NA and rumination at the previous time-point (*t-1*). Like before these associations were allowed to differ between individuals (i.e., random means and slopes) and scores were person-mean centered.

Using the whole sample, we then estimated the effect of group membership on the between level (see Figure 4b) on the autoregressive and cross-lagged parameters on the within-person level (dichotomous; 1 = formerly depressed participants, 0 = non-clinical controls):

$$\mu_{NA,\,i} = \gamma_{00} + \gamma_{01}\,\mathrm{Group}_i + u_{0i}$$

$$\mu_{Rumination,\,i} = \gamma_{10} + \gamma_{11}\,\mathrm{Group}_i + u_{1i} \qquad \text{(eq. 3)}$$

$$\varphi_{1i} = \gamma_{20} + \gamma_{21}\,\mathrm{Group}_i + u_{2i}$$

$$\varphi_{2i} = \gamma_{30} + \gamma_{31}\,\mathrm{Group}_i + u_{3i}$$

$$\varphi_{3i} = \gamma_{40} + \gamma_{41}\,\mathrm{Group}_i + u_{4i}$$

$$\varphi_{4i} = \gamma_{50} + \gamma_{51}\,\mathrm{Group}_i + u_{5i}$$

where $\gamma_{00\text{-}50}$ is the fixed average of the parameters and u_i is the individual deviations from these effects. On the between level, group membership, denoted as γGroup, was included as a predictor of the person-specific means and person-specific autoregressive and cross-lagged associations. All the parameters were allowed to covary with each other.

To test whether habitual characteristics (HINT) was a predictor of mood-reactive rumination in formerly depressed participants, we computed the cross-lagged model (Figure 4) using HINT instead of group membership as our between-level predictor (eq. 3) of the autoregressive and cross-lagged associations between affect and rumination on the within-person level (eq. 1). If fluctuations in NA trigger subsequent ruminative thinking as a function of habit, stronger φNA→Rum associations should be associated with greater habitual characteristics (HINT).

We also explored if mood-reactive rumination in formerly depressed participants was associated with indicators of depression recurrence (age of depression onset, number of episodes, stability of remission) and history of early-life stress (cumulative early-life stress, perceived stress severity, history of physical, sexual, or emotional abuse). We first computed the cross-lagged model (Figure 4a) in RFDs and entered each exploratory variable individually on the between-level (eq. 3), as predictors of the autoregressive and cross-lagged associations on the within-person level (eq. 1). We then explored whether the effect of each variable was moderated by habitual characteristics (HINT) by simultaneously entering each individual variable (γVAR) along with HINT on the between-level as well as adding an interaction term HINT*γVAR, created by multiplying each variable by scores on HINT (no correction for multiple testing). While 8.5% of RFDs reported no stressful early-life event, the rest reported one (28%), two (26%), three (16%), four (5%), five (8.5%), six (7%), or seven (1%) events. Due to the low number of RFDs reporting 4 or more stressful early-life events, they were collapsed into one category, resulting cumulative stress scores between 0 and 4. When analysing the models for subgroups of early-life events, events were dummy coded (1 = history of physical, sexual, or emotional abuse, 0 = no history of physical, sexual, or emotional abuse).

3 Results

3.1 Study 1

3.1.1 Trait Rumination and Habitual Characteristics

Descriptive statistics for self-report measures and experimental tasks are presented in Table 1. To determine whether the heightened disposition to engage in ruminative brooding was associated with greater habitual characteristics bivariate zero-order correlations between trait rumination (RRS) and self-report measures of habits were computed (see Table 2). As expected, HINT was positively correlated with ruminative brooding but not ruminative reflection, indicating that only brooding shares habitual characteristics with negative thinking. The same pattern was observed in the relationship between rumination and the automaticity and routine scores of the COHS, where brooding, but not reflection, was significantly and positively correlated with scores on both facets. Thus, heightened ruminative brooding, but not reflection, was associated with greater habitual characteristics of negative thinking and general propensity to habitual responding.

Table 1. Descriptive statistics of self-report questionnaires and the rumination-induction and habit-control tasks used in study 1 (*N* = 115).

	Mean (SD)	Range
Self-report questionnaires		
BDI-II	15.25 (10.16)	0-43
RRS	49.21 (11.79)	24-82
Brooding	11.21 (3.43)	5-20
Reflection	10.08 (3.42)	5-18
HINT	51.33 (16.72)	12-84
COHS Automaticity	33.53 (7.71)	17-51
COHS Routine	55.72 (10.27)	24-79
Rumination-induction task		
Mood		
T1: Baseline	57.64 (26.99)	1-138
T2: Post-mood manipulation	83.47 (32.50)	1-147
T3: Post-rumination induction	69.43 (29.47)	0-152
Worthlessness/incompetency		
T1: Baseline	74.39 (55.07)	0-207
T2: Post-mood manipulation	83.13 (60.32)	0-204
T3: Post-rumination induction	76.13 (65.09)	0-242
Unlovability/unacceptability		
T1: Baseline	66.19 (52.23)	0-190
T2: Post-mood manipulation	77.00 (60.79)	0-251
T3: Post-rumination induction	74.92 (62.26)	0-245
Habit-control task		
Slips-of-action test		
valued outcome	89.83 (9.93)	60-100
devalued outcome	28.08 (25.12)	0-97
Baseline test		
valued outcome	96.15 (4.65)	76-100
devalued outcome	14.09 (13.41)	0-100

Note. HINT = Habit Index of Negative Thinking; COHS Automaticity = The Creature of Habit Scale - automaticity subscale; COHS Routine = The Creature of Habit Scale - routine subscale; Brooding = Rumination Responses Scale - brooding subscale; Reflection = Rumination Responses Scale – ruminative reflection subscale; RRS = Rumination Responses Scale - total score; BDI-II = Becks Depression Inventory - II; T1 = Time 1; T2 = Time 2; T3 = Time 3.

Table 2. Bivariate correlations between RRS, HINT, and COHS scores in study 1 (N = 115).

	RRS brooding	RRS reflection
	r(113)	r(113)
HINT	.428**	.157
COHS automaticity	.294*	.174
COHS routine	.311**	.069

* p<0.01.
** p<0.001.

Note. HINT = Habit Index of Negative Thinking; Automaticity = The Creature of Habit Scale - automaticity subscale; Routine = The Creature of Habit Scale - routine subscale; DSI = Devaluation Sensitivity Index; Brooding = Rumination Responses Scale - brooding subscale; Reflection = Rumination Responses Scale – ruminative reflection subscale.

3.1.2 Rumination-Induction and Habitual Characteristics

Two participants did not follow the instructions for the rumination task, since both had multiple ratings of mood and negative self-judgements on each measurements occasion. Their data was therefore removed, leaving data from 113 subjects to be analysed for the rumination task.

Mood manipulation. A paired samples t-test confirmed an expected increase in dysphoric mood from baseline (Time 1) to post-mood manipulation (Time 2) (t(114) = -9.768, p < .001, CI = -30.22, -20.82, d = 1.027; Table 1). There was also a significant increase from Time 1 to Time 2 in negative self-judgements of worthlessness/incompetency (t(114) = -2.609, p = .010, CI = -15.38, -2.10, d = 0.243) and unacceptability/unlovability (t(114) = -3.613, p < .001, CI = -25.99, -6.96, d = 0.165). The mood manipulation therefore had a detrimental effect on both mood and the evaluation of self-worth (Table 1).

Rumination-induction. To test the hypothesis that greater habitual characteristics (HINT) and habit propensity (COHS) would be associated with greater persistence of dysphoric mood during rumination-induction, a three-step hierarchical regression using post-rumination induction (Time 3) mood scores as the dependent variable was performed. The results are summarized in Table 3. Mood scores at Time 2 were entered at step one to control for mood at the start of the rumination-induction[1]. Given the high correlation between self-report measures of ruminative brooding and habit in the current study, ruminative brooding (RRS) was entered at step 2 as a more conservative test of the relation between the effects of rumination induction and habitual responding. Ruminative brooding (RRS) entered at step two, significantly added to the model and was associated with greater persistence of dysphoric mood. Finally, HINT, entered at step three, was a significant predictor of greater persistence of dysphoric mood over and above all previously entered variables. Neither COHS routine nor automaticity scores significantly contributed to the prediction of mood when entered simultaneously at step three instead of HINT (all p_s >.37). In summary, after controlling for ruminative brooding, habitual characteristics of negative thinking (HINT), but not general automatic and routine response tendencies (COHS), significantly predicted greater persistence of dysphoric mood following rumination-induction.

[1] Another option would have been to control for mood scores at Time 1. However, this might confound changes during the rumination-induction with the initial shift in mood and cognition attributable to the mood-induction, which has been found to be related to other vulnerability factors in depression (e.g., cognitive reactivity, mood reactivity, and emotion regulation strategies). It was therefore decided to control for T2 as a more conservative test of the relation between habit and rumination-induction.

Table 3. Result from hierarchical regression analyses (final step) using ruminative brooding, habitual characteristics of negative self-thinking, and general habitual response tendencies to predict mood and negative self-judgement scores in the rumination-induction task in study 1 (N = 113).

	B	SE B	Beta
DV: Mood, T3			
Step 1 ($\Delta R^2 = 0.658^{***}$)			
Mood, T2	0.654	0.052	0.721^{***}
Step 2 ($\Delta R^2 = 0.029^{**}$)			
Brooding	1.177	0.505	0.137^{*}
Step 3 ($\Delta R^2 = 0.012^{*}$)			
HINT	0.224	0.108	0.126^{*}
DV: Worthlessness/incompetency, T3			
Step 1 ($\Delta R^2 = 0.766^{***}$)			
Worthlessness/incompetency, T2	0.910	0.065	0.842^{***}
Step 2 ($\Delta R^2 = 0.009^{*}$)			
Brooding	2.123	0.974	0.112^{*}
Step 3($\Delta R^2 = 0.000$)			
HINT	-0.091	0.235	-0.023
DV: Unlovability/unacceptability, T3			
Step 1 ($\Delta R^2 = 0.777^{***}$)			
Unlovability/unacceptability, T2	0.847	0.055	0.827^{***}
Step 2 ($\Delta R^2 = 0.004$)			
Brooding	1.005	0.912	0.055
Step 3 ($\Delta R^2 = 0.003$)			
HINT	0.239	0.203	0.064

Note. HINT = Habit Index of Negative Thinking; Brooding = Rumination Responses Scale - brooding subscale; T2 = Time 2; T3 = Time 3.

* $p<0.05$.

** $p<0.01$.

*** $p<0.001$.

Next it was examined whether greater habitual characteristics were associated with a greater persistence of negative self-judgements during rumination-induction. The three-step regression analysis was repeated with Time 3 negative self-judgements as the dependent variable (see Table 3). The results showed, that for worthlessness/incompetency as the outcome, ruminative brooding (step two), but not HINT (step three), emerged as a significant predictor after controlling for Time 2 worthlessness/incompetency scores. Neither ruminative brooding nor HINT added significantly to the prediction of negative self-judgements when unacceptability/unlovability was

the outcome. When performing the same analyses using COHS routine and automaticity scores, neither significantly added to the prediction of worthlessness/incompetency nor unacceptability/unlovability (all p_s > .44). Thus, only ruminative brooding showed a significant association with the detrimental effects of rumination-induction on the evaluation of self-worth.

3.1.3 Habitual Characteristics and the Immediate Response to Dysphoric Mood

To assess the specificity of these findings, it was also explored whether habitual characteristics (HINT) and habit propensity (COHS) were related to the immediate effects of the mood manipulation more generally. In the rumination task, Time 2 mood and negative self-judgement scores were regressed on the habit indices using six three-step hierarchical regressions. When controlling for Time 1 mood and negative self-judgement scores (step one), ruminative brooding, entered at step two, did not add to the prediction of Time 2 mood and negative self-judgements (all p_s > .216). HINT, entered at step three, emerged as a significant predictor of Time 2 mood (β = .478, p = .002, ΔR^2 = .050, p = .002, 95% CI = 0.175, 0.781), worthlessness/incompetency (β = .243, p < .001, ΔR^2 = .038, p < .001, 95% CI = 0.404, 1.365, and unacceptability/unlovability (β = .127, p = .034, ΔR^2 = .011, p = .034, CI = 0.035, 0.898). However, neither COHS routine nor COHS automaticity, simultaneously entered at step three, significantly added to the prediction of Time 2 mood and negative self-judgements (all p_s > .10). Therefore, greater habitual characteristics of negative thinking, but not more general habitual response tendencies nor ruminative brooding, were associated with greater immediate shifts in dysphoric mood and negative self-judgements in response to the mood manipulation.

3.1.4 Ruminative Disposition and Habit-Directed Behaviour Control

Finally, it was investigated whether a heightened ruminative disposition was associated with a greater habit relative to goal-directed behaviour control using the FFG outcome-devaluation task. There was a significant main effect of block in the FFG instrumental learning stage (mixed ANCOVA, F(4.243, 462.453) =11.436, p < 0.001, partial η^2 =.265), but no significant interaction between the effect of block and the rumination indices or BDI-II. This confirms that discriminative performance improved during the learning phase

of the task and at a rate independent of the degree of ruminative disposition or depression. As expected, participants responded significantly more often to stimuli associated with valued outcome than stimuli related to devalued outcome; on both the slips-of-action test (89.8% vs. 28.1%; paired samples t-test, $t(114) = 21.013$, $p < .001$, CI = 55.9, 67.6, $d = 1.959$) and the baseline test (96.2% vs. 14.1%; paired samples t-test, $t(114) = 52.720$, $p < .001$, CI = 79.0, 85.1, $d = 4.919$).

Hierarchical linear regression, with slips-of-action DSI as the outcome, showed that when baseline DSI (β = .424, $p < .001$, $\Delta R^2 = .177$, $p < .001$, CI = 0.478, 1.122) was entered at step one, to control for general test performance variables, followed by ruminative brooding (β = -.016, $p = .871$, $\Delta R^2 = .001$, CI = -1.762, 1.410) at step two, and rumination-induction change scores in mood (β = -.172, $p = .059$, CI = -0.568, 0.08) at step three, the baseline DSI was the only significant predictor of reliance on habit relative to goal-directed learning (slips-of-action DSI). The same pattern was found when entering rumination-induction change scores in worthlessness/incompetency and unacceptability/unlovability at step three (all $p_s > .14$). Thus, a heightened ruminative disposition was not characterized by greater habit relative to goal-directed behaviour control. Analysing first-order partial correlations, while controlling for the baseline DSI, showed that slips-of-action DSI was not related to HINT ($r(113) = -.002$, $p = .979$), nor COHS routine, ($r(113) = -.133$, $p = .159$), or automaticity ($r(113) = .084$, $p = .375$).

3.2 Study 2

3.2.1 Preliminary Analyses of mobile EMA data

In study 2 participants completed a total of 2710 alerts during the EMA assessment. Mean number of completed alerts was 33.1 (SD 11.4; range 10-53). See Table 4 for descriptive statistics. HINT was positively correlated with ruminative brooding (RRS), indicating that greater habitual characteristics are associated with a heightened ruminative disposition. On the other hand, HINT, was not correlated with average levels of momentary rumination. As we shall see, this is an example of how time-invariant means are ill-suited at capturing meaningful within-person variation across time.

Table 4. Descriptive statistics study 2

			1	2	3	4	5	6
Trait measures	1	Depressive Symptoms (BDI-II)		0.60***	0.61***	0.54***	-0.42***	0.21*
	2	Ruminative Brooding (RRS-B)			0.51***	0.44***	-0.34***	0.28**
	3	Habitual Characteristics (HINT)				0.55***	-0.32**	0.19
EMA measures	4	Negative Affect (NA)[a]					-0.53***	0.28**
	5	Positive Affect (PA)[a]						-0.03
	6	Momentary Rumination (MRSI-A)						
M			14.88	11.11	51.76	4.33	7.95	6.95
SD			10.08	3.40	16.82	0.80	1.58	3.02
Range			0-50	5-20	12-84	3-15	3-15	3-21

Note. Pearson correlation, p <0 .001 '***', p <0 .01 '**', p <0.05 '*' (alpha = 0.05)
BDI-II = Beck Depression inventory; RRS = Ruminative Response Scale; HINT = Habit-Index of Negative Thinking; MRSI-A = Momentary Ruminative Self-Focus Inventory

3.2.2 Daily Affect and Rumination Across Time

The standardized effects and variances are presented in Table 5 and their corresponding paths are visualized in Figure 3 in the methods section. Across both models, the autoregressive values (the effect of the variables on themselves) for NA (φNA→NA; B = 0.350) and PA (φPA→PA; B = 0.427) were significant, indicating carry-over (inertia) of both affective states from one moment to the next. The autoregressive effect for rumination (MRSI-A) was also significant for both models (φRum→Rum; Bs = 0.257 and 0.299) indicating that once initiated, rumination tended to persist.

The cross-lagged values (the effect of the variables on each other over time) revealed paths from affect to rumination, in both models, when controlling for initial levels of rumination (Table 5). The results show that individuals with heightened NA at one moment engaged in more rumination on the next measurement occasion (φNA→Rum; B = 0.118), and similarly, that a decline in PA was also predictive of greater rumination at the next measurement (φPA→Rum; B = -0.078). Thus, for both negative and positive affect, a within-person deviation from one's own mean level of affect was associated with a subsequent within-person change in rumination.

Table 5. Habitual characteristics of negative thinking (HINT) predicting the reciprocal association between momentary rumination (MRSI-A) and affect (NA/PA) over time in study 2. Standardized effects.

	Negative Affect				Positive Affect		
	B	SD	95% CI		B	SD	95% CI
Means				Means			
μ NA	5.02*	0.54	[4.04, 6.20]	μ PA	4.48*	0.39	[3.73, 5.28]
μ RUM	2.07*	0.20	[1.69, 2.47]	μ RUM	2.06*	0.20	[1.68, 2.45]
Autoregression				Autoregression			
φ NA→NA	0.35*	0.03	[0.30, 0.40]	φ PA→PA	0.43*	0.03	[0.37, 0.48]
φ RUM→RUM	0.26*	0.03	[0.20, 0.31]	φ RUM→RUM	0.30*	0.03	[0.24, 0.35]
Cross-lagged slopes				Cross-lagged slopes			
φ NA→RUM	0.12*	0.03	[0.06, 0.18]	φ PA→RUM	-0.08*	0.03	[-0.13, -0.03]
φ RUM→NA	0.05	0.03	[-0.01, 0.10]	φ RUM→PA	-0.03	0.03	[-0.09, 0.02]
Effect of HINT on…				Effect of HINT on…			
μ NA	0.35*	0.07	[0.20, 0.48]	μ PA	-0.20*	0.07	[-0.34, -0.05]
μ RUM	0.11	0.07	[-0.03, 0.25]	μ RUM	0.12	0.07	[-0.03, 0.26]
φ NA→NA	0.16	0.09	[-0.01, 0.33]	φ PA→PA	0.09	0.10	[-0.11, 0.29]
φ RUM→RUM	-0.04	0.09	[-0.20, 0.13]	φ RUM→RUM	-0.02	0.09	[-0.19, 0.15]
φ NA→RUM	0.22*	0.09	[0.03, 0.39]	φ PA→RUM	-0.30*	0.12	[-0.53, -0.08]
φ RUM→NA	0.09	0.11	[-0.12, 0.31]	φ RUM→PA	0.03	0.15	[-0.28, 0.32]
Variances				Variances			
$\Psi\mu$ NA	0.88*	0.05	[0.77, 0.96]	$\Psi\mu$ PA	0.96*	0.03	[0.88, 1.00]
$\Psi\mu$ RUM	0.98*	0.02	[0.94, 1.00]	$\Psi\mu$ RUM	0.98*	0.02	[0.93, 1.00]
$\Psi\varphi$ NA→NA	0.97*	0.03	[0.89, 1.00]	$\Psi\varphi$ PA→PA	0.98*	0.02	[0.92, 1.00]
$\Psi\varphi$ RUM→RUM	0.99*	0.01	[0.96, 1.00]	$\Psi\varphi$ RUM→RUM	0.99*	0.01	[0.96, 1.00]
$\Psi\varphi$ NA→RUM	0.95*	0.04	[0.85, 1.00]	$\Psi\varphi$ PA→RUM	0.89*	0.07	[0.72, 0.99]
$\Psi\varphi$ RUM→NA	0.98*	0.03	[0.91, 1.00]	$\Psi\varphi$ RUM→PA	0.98*	0.03	[0.88, 1.00]

**significance* *is based on the Credible Interval (CI) not containing zero*

Note. RUM = Momentary rumination (MSRI-A), NA = Negative Affect, PA = Positive Affect

Surprisingly, no paths were found from rumination to either NA (φRum→NA; B = 0.038) nor PA (φRum→PA; B = -0.029) meaning that rumination did not predict subsequent changes in affect[2]. The significant variance components in both models (see Ψ values) revealed marked individual variation in all the effects (see Table 5).

The correlations between within-level effects are visualized in Figure 5. Blue connections represent positive correlations, and red connections represent negative correlations. Individuals with a higher average level of NA tended to have more moment-to-moment carry-over in their NA. This is evident in the positive correlation (r = 0.187) between the mean μNA and the autoregressive parameter φNA→NA. It was also observed that when people ruminated to a greater extent in response to heightened NA, there was more moment-to-moment carry-over in affect. This appears in the positive correlation (r = 0.109) between the autoregressive parameter φNA→NA and the cross-lagged parameter φNA→Rum.

[2] An analysis of the data revealed that rumination does predict subsequent changes in NA and PA when excluding the between-level predictor HINT. This is consistent with prior findings (e.g., Moberly & Watkins, 2008) showing rumination to predict subsequent changes in affect. However, when accounting for the effects of HINT, and associated parameters, other paths become more predominant.

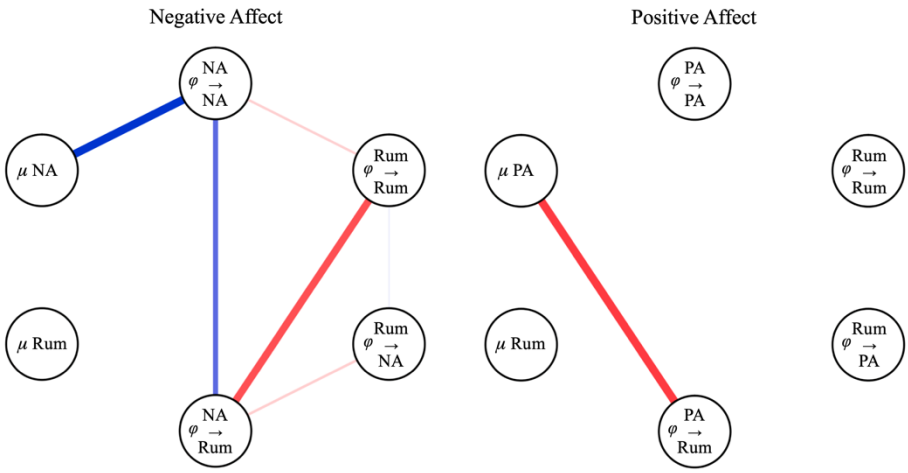

Figure 5. The temporal relationship between momentary rumination (MRSI-A), negative affect (NA) and positive affect (PA) in study 2. A visual representation of the correlations between means, autoregressive and cross-lagged parameters in the two models. Only correlations whose 95% credible interval did not include zero are included. Blue connections represent positive correlations and red connections represent negative correlations. The thickness of the lines indicate correlation strength. This correlation structure was created with qgraph in R (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012; R Core Team, 2018).

Also noteworthy, the negative correlation (r = -0.171) between the cross-lagged coefficient φNA→Rum and the autoregressive parameter φRum→Rum implies that when people ruminate to a greater extent in response to heightened negative affect, there tends to be less carry-over of rumination from one moment to the next. Also note the finding (although weaker) that less carry-over of rumination was associated with greater emotional inertia (φNA→NA and φRum→Rum; r = -0.044), suggesting that reactive rather than static levels of ruminative thinking tend to be associated with greater emotional inertia. Also, greater mood-linked rumination was to some extent associated with preceding rumination having less effect on mood (φNA→Rum and φRum→NA; r = -0.046), suggesting that when mood-linked rumination is present, any ruminative thinking occurring prior to that tends to have a smaller effect on mood.

Finally, the dynamic parameters were less intertwined for positive than negative affect, with only one significant association (see Figure 2). Mean μPA and the cross-lagged coefficient PA→Rum were negatively correlated (r = -0.171), suggesting that greater rumination in response to decreased PA was associated with lower average levels of PA.

3.3. Habitual characteristics and the relationship between affect and rumination across time.

For negative affect, HINT was significantly associated with larger cross-lagged parameters (φNA→Rum; B = 0.217; see Table 5). This relationship is depicted in Figure 6 which shows that when associated with greater trait habitual characteristics, a momentary increase in NA is more likely to evoke heightened rumination on the next measurement occasion. This effect corresponds to an increase of 0.015 (absolute value) in the cross-lagged parameter φNA→Rum for each point increase in HINT.

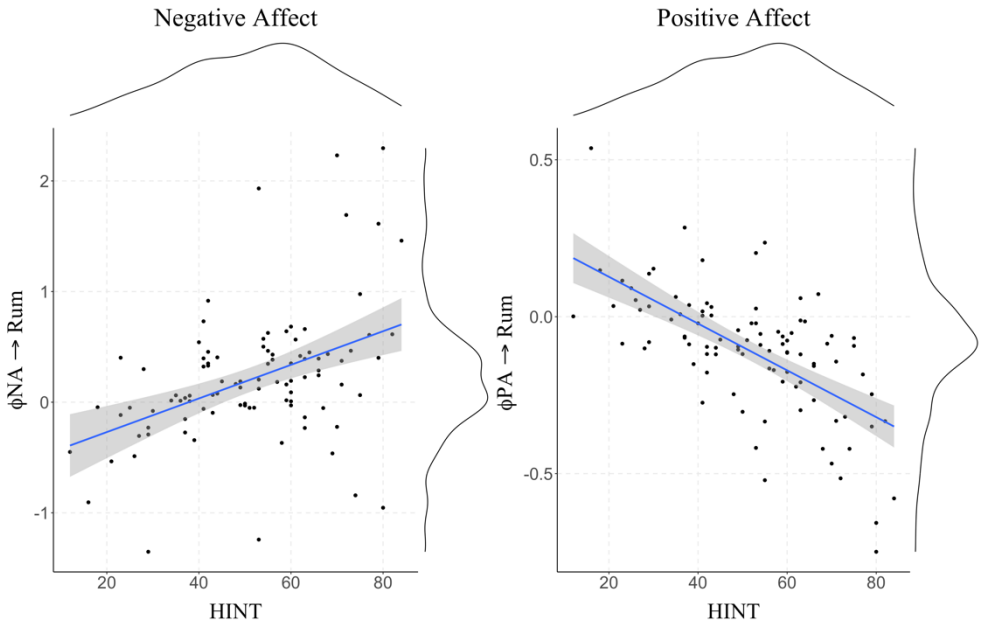

Figure 6. Momentary negative (NA) and postive affect (PA) predicting rumination on the next measurement occasion given the individuals' habitual characteristics (HINT) in study 2. Raw estimates of cross-lagged parameters φAffect→Rum for positive and negative affect are shown. Each dot corresponds to one participant. Marginal plots show density distributions for HINT and the cross-lagged parameters.

Also, for positive affect, HINT was significantly associated with larger (negative) cross-lagged parameters (φPA→Rum; B = -0.304). Figure 3 shows that, for PA, larger negative coefficients can be found at the higher end of the HINT distribution, thus, *a decrease in PA* is more likely to evoke heightened rumination on the next measurement occasion when associated with greater habitual characteristics. This corresponds to a decrease of -0.007 (absolute value) in the cross-lagged parameter φPA→Rum for each point increase in HINT. As evidenced by the standardized estimates, this effect was larger for PA than for NA.

Finally, HINT was associated with higher average levels of NA (μ = 0.345) and lower average levels of PA (μ = -0.197), indicating that when accounting for the temporal relationships, HINT was associated with lower average levels of both NA and PA. HINT was not significantly associated with other parameters in the models.

These results were followed with additional analyses to investigate their robustness. The current findings remained unchanged when the results were detrended to control for the possible influence of time on the measurements[3]. Ruminative brooding, when entered at the between level instead of HINT in the models above, was not a significant predictor of the cross-lagged parameter φNA→Rum (B = 0.125; 95% CI = [-0.05, 0.29.]) nor φPA→Rum (B = 0.018; 95% CI = [-0.21, 0.25]). Depression symptoms (BDI-II), however, were predictive of a greater cross-lagged parameter for φNA→Rum (B = 0.195; 95% CI = [0.03, 0.36.]) but not for φPA→Rum (B = -0.082; 95% CI = [-0.30, 0.15]).

HINT, ruminative brooding, and BDI-II were moderately correlated in study 2 (see Table 4). The models above were therefore computed again using the residual variance of HINT, when regressed on either ruminative brooding or BDI-II, to see whether the results depended on the shared

[3] The time of measurement was inserted in the within-part of the models to control for trends or non-stationary of the data during the measurement period. The results remained unchanged for both models of positive and negative affect.

variance between the measures (See Table 6). HINT (residualized by brooding) still remained a unique predictor of the cross-lagged parameters φNA→Rum (B = 0.154; 95% CI = [0.02, 0.31.]) and φPA→Rum (B = -0.341; 95% CI = [-0.59, -0.10]). When accounting for depressive symptoms, HINT (residualized by BDI-II) still remained a unique predictor of the cross-lagged parameter φPA→Rum (B = -0.342; 95% CI = [-0.62, -0.09.]) but not for φNA→Rum (B = 0.05; 95% CI = [-0.13, 0.24]) suggesting that HINT shares predictive variance with BDI-II.

Table 6. Full model result for HINT (residualized) when regressed on ruminative brooding (RRS-B) or depression symptom severity (BDI-II) in study 2. HINT residualized predicting the reciprocal association between affect (NA/PA) and rumination (MRSI-A**)** over time. Standardized effects.

HINT (residualized by RRS-B)

	Negative Affect				Positive Affect		
	B	SD	95% CI		B	SD	95% CI
Means				Means			
μ NA	4.71*	0.50	[3.80, 5.75]	μ PA	4.41*	0.39	[3.66, 5.20]
μ RUM	2.05*	0.20	[1.67, 2.45]	μ RUM	2.04*	0.20	[1.67, 2.44]
Autoregression				Autoregression			
φ NA→NA	0.35*	0.03	[0.30, 0.40]	φ PA→PA	0.43*	0.03	[0.37, 0.48]
φ RUM→RUM	0.26*	0.03	[0.20, 0.31]	φ RUM→RUM	0.31*	0.03	[0.25, 0.36]
Cross-lagged slopes				Cross-lagged slopes			
φ NA→RUM	0.12*	0.03	[0.06, 0.18]	φ PA→RUM	-0.07*	0.03	[-0.12, -0.02]
φ RUM→NA	0.04	0.03	[-0.01, 0.09]	φ RUM→PA	-0.03	0.03	[-0.08, 0.02]
Effect of HINT on…				Effect of HINT on…			
μ NA	0.25*	0.08	[0.10, 0.39]	μ PA	-0.12	0.08	[-0.26, 0.03]
μ RUM	0.03	0.07	[-0.11, 0.17]	μ RUM	0.04	0.07	[-0.10, 0.19]
φ NA→NA	0.07	0.09	[-0.10, 0.24]	φ PA→PA	0.10	0.10	[-0.10, 0.30]
φ RUM→RUM	-0.06	0.09	[-0.23, 0.11]	φ RUM→RUM	-0.13	0.09	[-0.30, 0.05]
φ NA→RUM	0.15*	0.09	[0.02, 0.31]	φ PA→RUM	-0.34*	0.13	[-0.59, -0.10]
φ RUM→NA	0.14	0.11	[-0.07, 0.36]	φ RUM→PA	-0.01	0.16	[-0.33, 0.29]
Variances				Variances			
$\Psi\mu$ NA	0.93*	0.04	[0.85, 0.99]	$\Psi\mu$ PA	0.98*	0.02	[0.93, 1.00]
$\Psi\mu$ RUM	0.99*	0.01	[0.97, 1.00]	$\Psi\mu$ RUM	0.99*	0.01	[0.97, 1.00]
$\Psi\varphi$ NA→NA	0.99*	0.02	[0.94, 1.00]	$\Psi\varphi$ PA→PA	0.98*	0.03	[0.91, 1.00]
$\Psi\varphi$ RUM→RUM	0.99*	0.01	[0.95, 1.00]	$\Psi\varphi$ RUM→RUM	0.98*	0.03	[0.91, 1.00]
$\Psi\varphi$ NA→RUM	0.97*	0.03	[0.91, 1.00]	$\Psi\varphi$ PA→RUM	0.87*	0.09	[0.65, 0.99]
$\Psi\varphi$ RUM→NA	0.96*	0.03	[0.90, 1.00]	$\Psi\varphi$ RUM→PA	0.98*	0.04	[0.87, 1.00]

HINT (residualized by BDI-II)

	Negative Affect				Positive Affect		
	B	SD	95% CI		B	SD	95% CI
Means				Means			
μ NA	4.61*	0.50	[3.70, 5.67]	μ PA	4.36*	0.39	[3.62, 5.16]
μ RUM	2.05*	0.20	[1.67, 2.45]	μ RUM	2.04*	0.20	[1.66, 2.43]
Autoregression				Autoregression			
φ NA→NA	0.35*	0.03	[0.30, 0.40]	φ PA→PA	0.43*	0.03	[0.37, 0.48]
φ RUM→RUM	0.26*	0.03	[0.20, 0.31]	φ RUM→RUM	0.31*	0.03	[0.25, 0.36]
Cross-lagged slopes				Cross-lagged slopes			
φ NA→RUM	0.13*	0.03	[0.06, 0.19]	φ PA→RUM	-0.07*	0.03	[-0.12, -0.02]
φ RUM→NA	0.04	0.03	[-0.01, 0.09]	φ RUM→PA	-0.03	0.03	[-0.08, 0.02]
Effect of HINT on…				Effect of HINT on…			
μ NA	0.15	0.08	[-0.07, 0.30]	μ PA	-0.04	0.08	[-0.19, 0.11]
μ RUM	0.03	0.07	[-0.12, 0.18]	μ RUM	0.03	0.07	[-0.12, 0.17]
φ NA→NA	-0.03	0.09	[-0.20, 0.15]	φ PA→PA	-0.03	0.11	[-0.24, 0.18]
φ RUM→RUM	-0.01	0.09	[-0.18, 0.17]	φ RUM→RUM	-0.10	0.10	[-0.28, 0.09]
φ NA→RUM	0.05	0.10	[-0.13, 0.24]	φ PA→RUM	-0.34*	0.14	[-0.62 -0.09]
φ RUM→NA	0.13	0.11	[-0.08, 0.35]	φ RUM→PA	-0.01	0.17	[-0.32, 0.33]
Variances				Variances			
$\Psi\mu$ NA	0.97*	0.02	[0.91, 1.00]	$\Psi\mu$ PA	0.99*	0.01	[0.96, 1.00]
$\Psi\mu$ RUM	0.99*	0.01	[0.97, 1.00]	$\Psi\mu$ RUM	0.99*	0.01	[0.97, 1.00]
$\Psi\varphi$ NA→NA	0.99*	0.01	[0.96, 1.00]	$\Psi\varphi$ PA→PA	0.99*	0.02	[0.94, 1.00]
$\Psi\varphi$ RUM→RUM	0.99*	0.01	[0.96, 1.00]	$\Psi\varphi$ RUM→RUM	0.98*	0.02	[0.92, 1.00]
$\Psi\varphi$ NA→RUM	0.99*	0.02	[0.94, 1.00]	$\Psi\varphi$ PA→RUM	0.87*	0.10	[0.61, 0.99]
$\Psi\varphi$ RUM→NA	0.97*	0.03	[0.88, 1.00]	$\Psi\varphi$ RUM→PA	0.97*	0.04	[0.87, 1.00]

******significance is based on the Credible Interval (CI) not containing zero*
Note. RUM = Momentary rumination (MSRI-A), NA = Negative Affect, PA = Positive Affect

3.3 Study 3

3.3.1 Sample Characteristics

Sample characteristics and demographics of both recurrent formerly depressed individuals and never-depressed clinical controls are presented in Table 8. RFDs had experienced an average of 7.1 (*SD* = 3.6) lifetime depressive episodes and mean age of first-episode onset was 18.1 (*SD* = 6.9) years. There were no significant differences between the groups concerning age (mean age of 36.8 vs 39.7), gender, relationship status, educational level, or current employment status (see Table 7). As might be expected, RFDs worked somewhat lower percentages compared to NCs. On average, RFDs reported a greater number of stressful early-life events and were more likely to have a history of abuse. RFDs also showed higher levels of depression (BDI-II), habitual-characteristics (HINT) and trait levels of brooding (RRS-brood). Non-completers (those who did not provide sufficient number of responses) did not significantly differ from the sample with regards

to age, gender ratio, relationship status, educational level, or employment status.

Table 7. Completers vs. non-completers with regards to demographics (study 3).

	Completers (n = 149)	Non-completers (n = 10)	
	M (SD)	M (SD)	Statistic
Age (years)	37.9 (11.3)	36.1 (12.3)	$t(10.05) = -0.443$, $p = 0.667$
Gender (males)	31	2	$X^2(1) = 0.004$, $p = 0.952$
Relationship status			$X^2(4) = 1.508$, $p = 0.825$
Married	57	5	
Single	40	3	
Relationship	13	0	
Cohabitation	36	2	
Other	3	0	
Education (final level)			$X^2(3) = 2.028$, $p = 0.567$
High school	13	2	
Gymnasium	51	3	
College, undergraduate	52	4	
College, graduate	33	1	
Employment status			$X^2(1) = 0.043$, $p = 0.837$
Employed	115	8	
Unemployed	34	2	
Employment percentage	81.9 (28.3)	57.9 (38.6)	$t(6.41) = -1.619$, $p = 0.154$

Table 8

Demographic and clinical characteristics of formerly depressed and healthy non-clinical controls.

	Formerly depressed (*n*=94)		Non-clinical controls (*n*=55)		Statistic	
Characteristic	*M (SD)*	%	*M (SD)*	%	*t*	X^2
Age (years)	36.8 (10.9)		39.7 (11.9)		*t*(147)=-1.492, *p*=0.138	
Gender (males)	19	20.2	12	22		X^2(1, *N*=149)=0.001, *p*=0.981
Relationship status						X^2(4, *N* = 149)=3.634, *p*=0.458
Married	34	36.2	23	42		
Single	30	32	10	18		
Relationship	8	9	5	9		
Cohabitation	20	21	16	29		
Other	2	2	1	2		
Education (final level)						X^2(3, *N*=149)=0.848, *p*=0.838
High school	7	7	6	11		
Gymnasium	34	36	17	31		
College, undergraduate level	33	35	19	35		
College, graduate level	20	21	13	24		
Employment status						X^2(1, *N*=149)=0.181, *p*=0.671
Employed	71	76	44	80		
Unemployed	23	24	11	20		
Employment percentage	79.6 (29)		87.2 (24.2)		*t*(105.09)=-1.692, *p*=0.094	
Student	36	38	18	33		X^2(1, *N*=149)=0.307, *p*=0.580
Age at depression onset (*M, SD*)	18.1 (6.88)					
Number of MDD episodes (*M, SD*)	7.14 (3.64)					
Stability of remission (*M, SD*)	0.957 (1.91)					
Cormorbid diagnosis						
Yes (at least one)	25					
No	69					
Total of comorbid diagnoses	24					
Anxiety disorders	27					
Eating disorders	1					
CTES						
Number of stressful events	2.43 (1.75)		1.55 (1.136)		*t*(147)=-3.205, *p*=0.002	
Severity	12.2 (10.1)		6.61 (7.23)		*t*(140.9)=-3.951, *p*<0.001	
History of physical, sexual, or emotional abuse	47	50	14	25.5		X^2(1, *N*=149)=7.661, *p*=0.006
HINT	62.2 (13)		32.2 (16.2)		*t*(147)=-12.389, *p*<0.001	
RRS-brood	11.6 (3.01)		6.85 (1.59)		*t*(145.81)=-12.463, *p*<0.001	
BDI	8.57 (5.97)		2.18 (2.82)		*t*(141.92)=-8.827, *p*<0.001	

Note. CTES=Childhood Traumatic Events Scale; HINT=Habit-Index of Negative Thinking; RRS-brood=Ruminative Response Scale - brooding; BDI-II=Beck Depression inventory

non-clinical controls.

3.3.2 Preliminary Analyses of mobile EMA data

Participants completed a total of 6008 EMA alerts (RFDs =3733, NCs = 2275). RFDs completed on average 66% (range = 20%-93%) of the EMA alerts compared to 69% (range = 20% - 95%) in the NCs, with no-significant difference between the groups, $t(107.5) = 0.86$, $p = 0.394$. Across time, ratings of momentary NA were significantly higher in RFDs ($M = 4.27$, $SD = 0.98$) than in NCs ($M = 3.28$, $SD = 0.32$), $t(123.3) = 9.02$, $p < .001$. In addition, RFDs demonstrated more moment-to-moment fluctuations in NA ($MSSD = 2.67$, $SD = 2.76$) compared to NCs ($MSSD = 0.87$, $SD = 1.14$), $t(135) = 5.58$, $p < .001$. The groups did not differ in their average level of momentary rumination ($M = 6.87$, $SD = 3.14$, in RFDs vs. $M = 6.10$, $SD = 3.57$, in NCs), $t(101.7) = 1.34$, $p = .185$. However, RFDs showed more pronounced moment-to-moment fluctuations in rumination ($MSSD = 16.61$, $SD = 12.21$) compared to NCs ($MSSD = 6.81$, $SD = 8.12$), $t(144.5) = 5.87$, $p < .001$. Mean levels of NA and rumination did not change as a function of time during the EMA assessment period[4].

Between-person correlations of trait and EMA measures are provided in Table 9. Momentary rumination (MRSI-A) was positively correlated with RRS-B ($r = 0.33$)[5] in RFDs but not NCs ($r = 0.17$). Momentary NA was moderately correlated with depressive symptoms (BDI-II) in both RFDs ($r = 0.28$) and NCs ($r = 0.32$). However, momentary rumination (MRSI-A) was positively correlated with habitual characteristics (HINT) only in RFDs ($r = 0.29$) but not in NCs ($r = -0.11$).

[4] There were no significant trends for either group in momentary levels of NA or rumination. No effects were found for the time of day (start and end of day), day of EMA, or time of measurement. The current results remained unchanged when time of measurement was inserted in the within-part of the models to control for trends or non-stationary of the data during the EMA assessment period.

[5] Correlations are based on within-person averages of NA and MRSI-A

Table 9. Between-person correlation of trait measures with mean levels of momentary negative affect (NA) and rumination (MRSI-A) in formerly depressed participants and non-clinical controls in study 3.

Formerly depressed participants (n = 94)			1	2	3	4	5
EMA	1	Negative Affect (NA)		0.24*	0.18*	0.28**	0.28**
	2	Momentary Rumination (MRSI-A)			0.33**	0.12	0.29**
Trait	3	Ruminative Brooding (RRS-B)				0.01	0.20**
	4	Depressive Symptoms (BDI-II)					0.28**
	5	Habitual Characteristics (HINT)					

Non-clinical controls (n = 55)			1	2	3	4	5
EMA	1	Negative Affect (NA)		0.17	0.44**	0.32*	0.38**
	2	Momentary Rumination (MRSI-A)			0.17	0.08	-0.11
Trait	3	Ruminative Brooding (RRS-B)				-0.01	0.37**
	4	Depressive Symptoms (BDI-II)					0.19
	5	Habitual Characteristics (HINT)					

Note. p <0 .001 '***', p <0 .01 '**', p <0.05 '*' (alpha = 0.05)
MRSI-A = Momentary Ruminative Self-Focus Inventory; RRS = Ruminative Response Scale; BDI-II = Beck Depression inventory; HINT = Habit-Index of Negative Thinking

3.3.3 Group Differences in Mood-Reactive Rumination in the Daily Life of RFDs and NCs

The effect of group on the temporal associations between NA and rumination is presented in Figure 7 and their corresponding paths are visualized in Figure 2 in the method section. Detailed model results are provided in Table 10. Group was a significant predictor of mood-reactive rumination (Group on φNA→Rum) during the EMA assessment period (B = 0.247, SD = 0.10, 95% CI = [0.04, 0.45]). The cross-lagged association between NA and subsequent rumination was significant in RFDs (φNA→Rum; B = 0.086, SD = 0.02, 95%

CI = [0.04, 0.13]) but not in NCs (B = -0.005, SD = 0.05, 95% CI = [-0.09, 0.09]), when controlling for both initial levels of rumination and the effect that rumination had on subsequent mood[6].

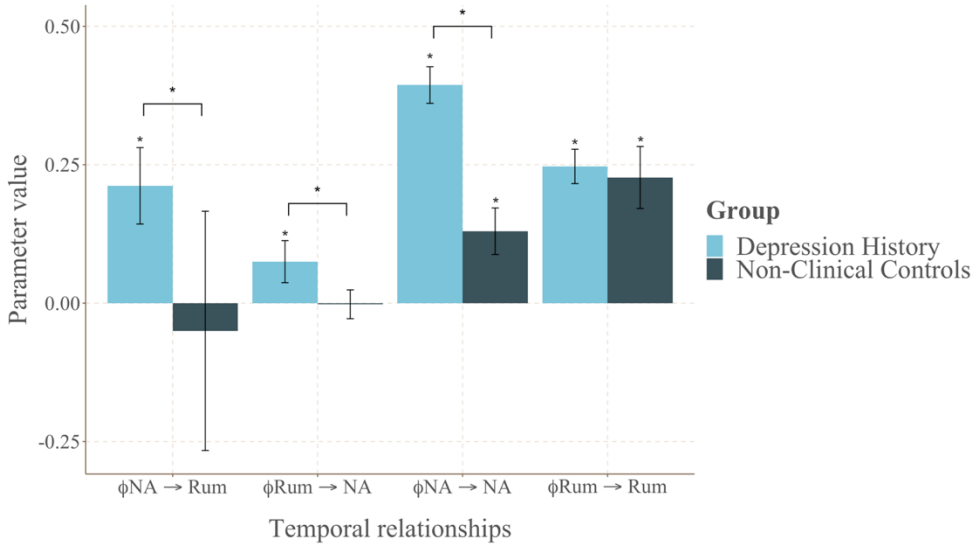

Figure 7. Temporal relationships between negative affect (NA) and momentary rumination (MRSI-A) in daily life (EMA assessment) in recurrent formerly depressed individuals compared to non-clinical controls (study 3). Point estimates (posterior means) of cross-lagged (φNA→Rum/φRum→NA) and autoregressive (φNA→NA/φRum→Rum) paths are shown. Error bars indicate the standard deviation of the posterior distributions. *Statistical significance is based on the 95% credible interval not containing zero.

[6] It should also be noted that the contemporaneous association between NA and rumination was stronger in RFDs (B = 0.197, SD = 0.02, 95% CI = [0.16, 0.23]) than in NCs (B = 0.171, SD = 0.02, 95% CI = [0.13, 0.21]) although both groups demonstrated a significant relationship.

Table 10. Group predicting the reciprocal association between negative affect (NA) and momentary rumination (MRSI-A) over time (EMA assessment) in study 3. Standardized effects.

Effect of group on…	B	SD	95% CI
μ NA	0.43*	0.05	[0.33, 0.53]
μ RUM	0.07	0.06	[-0.04, 0.19]
φ NA→NA	0.40*	0.07	[0.25, 0.53]
φ RUM→RUM	0.05	0.08	[-0.11, 0.20]
φ NA→RUM	0.25*	0.10	[0.04, 0.45]
φ RUM→NA	0.15*	0.06	[0.03, 0.27]

**significance is based on the Credible Interval (CI) not containing zero*

Note. Group was dummy coded in the analyses with 1 = formerly depressed participants and 0 = non-clinical controls

Mood-reactive rumination did not change as a function of time in either group during the EMA period[7]. Given the significant difference between groups in current depressive symptoms (see Table 8), BDI-II and group membership were simultaneously entered on the between-level, to control for possible confounds with current depressive status. Group membership still remained a significant predictor of greater mood-reactive rumination (Group on φNA→Rum; B = 0.260, SD = 0.12, 95% CI = [0.17, 0.51]). It should also be noted that group emerged as a significant predictor of the cross-lagged association between rumination and subsequent NA (see Figure 7; Group on φRum→NA; B = 0.148, SD = 0.06, 95% CI = [0.03, 0.27]), with increased

[7] Additional models found no effect for time of day, day of EMA, or time or measurement on mood-reactive rumination (all credible intervals contained zero). These were run using a cross-classified extension of the the two-level model that seperates the between-level into person-specific and time-specific effects, which is needed for the analysis of trends in between-level latent variables (see Asparouhov et al., 2018).

rumination leading to greater subsequent levels of NA (φRum→NA) in RFDs (B = 0.038; SD = 0.01, 95% CI = [0.02, 0.06]) but not in NCs (B = -0.022; SD = 0.03, 95% CI = [-0.08, 0.05]).

3.3.4 Habitual Characteristics Predict Mood-Reactive Rumination in Daily Life of RFDs

To test whether mood-reactive rumination is associated with habitual characteristics of negative thinking (HINT), a cross-lagged model using HINT as a between-level predictor was tested in RFDs where NA was shown to be a significant predictor of rumination across time. HINT was significantly associated with larger cross-lagged parameters between NA and subsequent rumination in RFDs (HINT on φNA→Rum; B = 0.253, SD = 0.12, 95% CI = [0.02, 0.49]). Detailed full model results for HINT are provided in Table 11. This relationship is depicted in Figure 8 which shows that when associated with greater trait habitual characteristics, a momentary increase in NA evoked heightened rumination on the next measurement occasion.

Table 11. Habitual characteristics of negative thinking (HINT) predicting the reciprocal association between negative affect (NA) and momentary rumination (MRSI-A) in formerly depressed participants (study 3). Standardized effects

Effect of HINT on…	B	SD	95% CI
μ NA	0.22*	0.08	[0.07, 0.37]
μ RUM	0.13	0.07	[-0.02, 0.27]
φ NA→NA	0.16	0.09	[-0.01, 0.33]
φ RUM→RUM	0.02	0.10	[-0.17, 0.22]
φ NA→RUM	0.25*	0.12	[0.02, 0.49]
φ RUM→NA	0.06	0.12	[-0.17, 0.29]

**significance is based on the Credible Interval (CI) not containing zero*

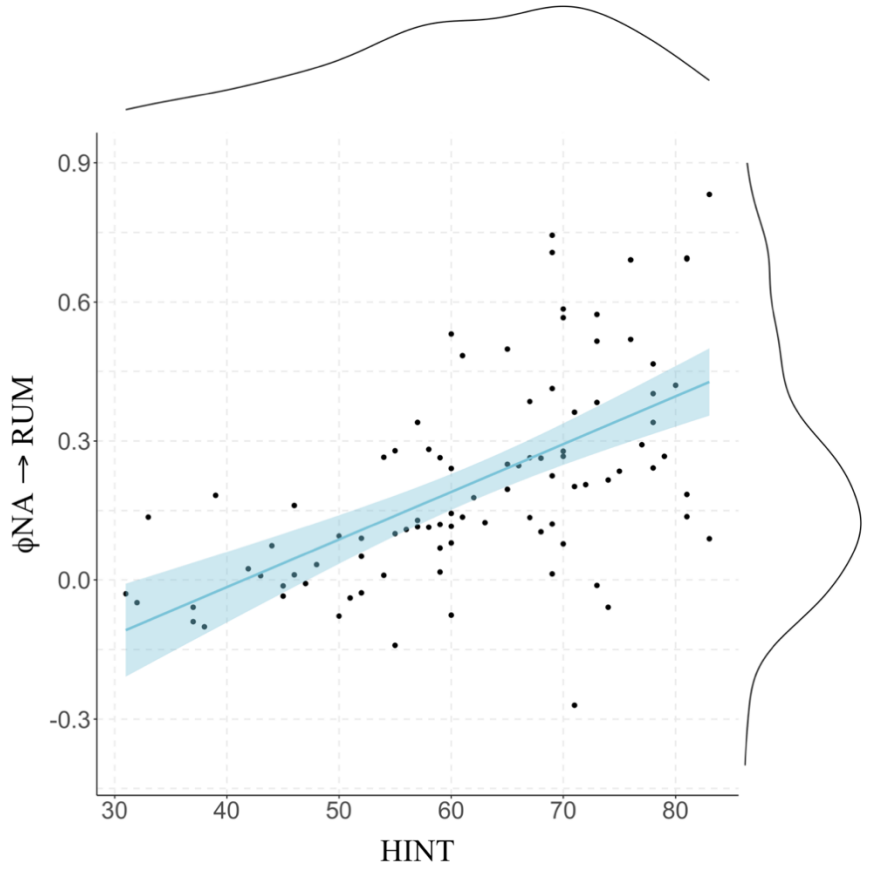

Figure 8. Negative affect (NA) predicting subsequent rumination (MRSI-A) in daily life (EMA assessment) in formerly depressed individuals as a function of habitual characteristics (HINT) in study 3. Raw estimates of cross-lagged parameters *φ*NA→Rum are shown. Each dot corresponds to one participant with a history of depression. Marginal plots show density distributions for HINT and the cross-lagged parameters.

Additional analyses were carried out to test the robustness of this findings. When controlling for RRS-brooding, entered simultaneously with HINT on the between-level, HINT still remained a significant predictor of cross-lagged path between NA and subsequent rumination (HINT on φNA→Rum; B = 0.282, SD = 0.12, 95% CI = [0.04, 0.51]) whereas RRS-brooding did not demonstrate a significant effect (RRS-brooding on φNA→Rum; B = -0.15, SD = 0.12, 95% CI = [-0.39, 0.09]). RRS-brooding, when entered as the only predictor in the model, was a significant predictor of average momentary levels of rumination (RRS-brooding on μRum; B = 0.184, SD = 0.07, 95% CI = [0.04, 0.32]), however, it did not significantly predict the cross-lagged path between NA and subsequent rumination (RRS-brooding on φNA→Rum; B = -0.09, SD = 0.12, 95% CI = [-0.34, 0.15]). Furthermore, when entering depressive symptoms simultaneously with HINT on the between-level, HINT still emerged as a significant predictor of greater mood-reactive rumination (HINT on φNA→Rum; B = 0.260, SD = 0.12, 95% CI = [0.17, 0.50]) whilst depressive symptoms did not (BDI-II on φNA→Rum; B = -0.01, SD = 0.12, 95% CI = [-0.23, 0.24]).

3.3.5 Exploratory Analyses: The Role of Depression Course and Early-Life Stress in Mood-Reactive Rumination in Daily Life of RFDs

It was also also explored whether mood-reactive rumination in daily life of RFDs was associated with early-life stress and depression course. Results of the main analyses are presented in Figure 9. Detailed results are provided in Table 12. As can be seen in Figure 9, depression course (number of depressive episodes, age of onset, stability of remission) did not emerge as significant predictors of mood-reactive rumination nor did habitual characteristics (HINT) moderate their effect to any significant degree.

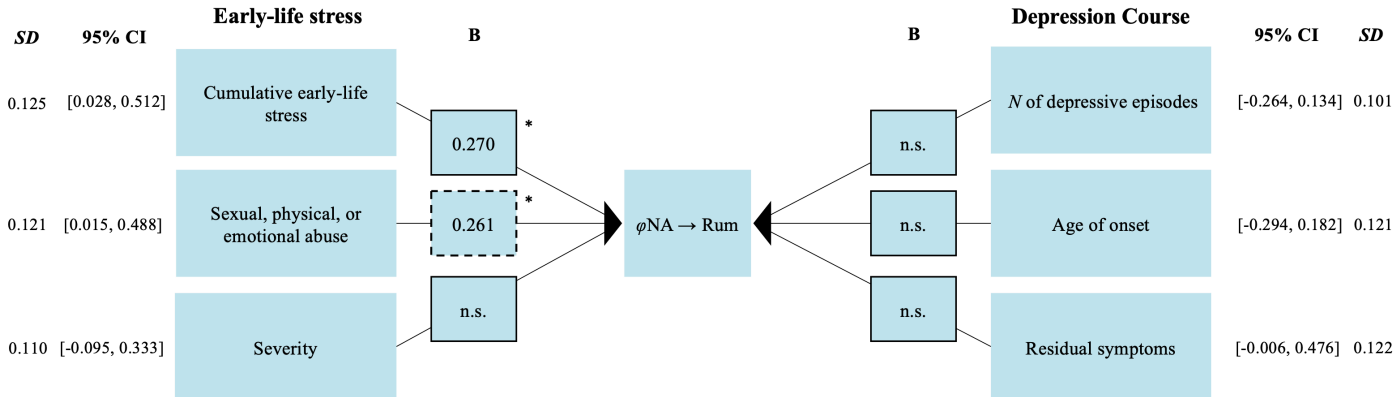

Figure 9. Early-life stress (CTES) and depression course (MINI depression module) predicting mood-linked rumination (φNA→Rum) in daily life (EMA assessment) in formerly depressed individuals (standardized effects) in study 3. Dashed lines signify effects moderated by habitual characteristics (HINT). *Statistical significance is based on the 95% credible interval not containing zero.

Self-reported severity of early-life stress did not emerge as a significant predictor of mood-reactive rumination. Cumulative early-life stress before the age of 17 (for descriptive statistics see Table 8) was, however, a significant predictor of larger cross-lagged associations between NA and subsequent rumination in RFDs (Cumulative stress on φNA→Rum; B = 0.270; see Figure 9). Additional analyses were carried out to assess if this finding was specific to the type of early-life stress in question. RFDs with a history of abuse (dummy coded as 1 or 0), demonstrated significantly greater mood-linked rumination compared to RFDs that did not report an early-life experience of abuse (Abuse on φNA→Rum; B = 0.261). Although cumulative early-life stress did not interact with self-reported habitual characteristics (HINT) in predicting mood-reactivity of daily ruminative thoughts (HINT x Cumulative stress on φNA→Rum; B = 0.01, SD = 0.13, 95% CI = [-1.5, 0.35]), a history of abuse did (HINT x Abuse on φNA→Rum; B = 0.332, SD = 0.15, 95% CI = [0.02, 0.60]). This relationship is depicted in Figure 10. Habitual characteristics of self-focused negative thinking (HINT) significantly predicted stronger temporal pairing between NA and subsequent rumination in participants reporting physical, sexual, or emotional abuse before age of 17, but not in RFDs reporting no such history of abuse.

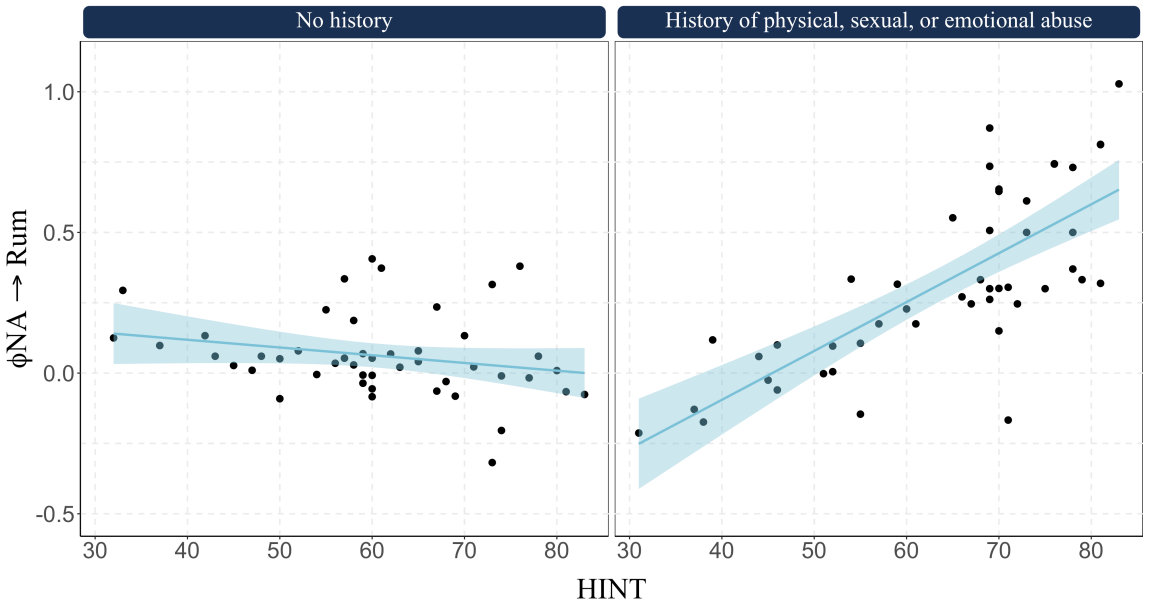

Figure 10. Habitual characteristics (HINT) moderating the effect of early-life stress (physical, sexual, or emotional abuse) on mood-linked rumination in the daily life (EMA assessment) of formerl depressed individuals (study 3). Raw estimates of cross-lagged parameters φNA→Rum are shown. Each dot corresponds to one participant with a history of depression.

Table 12. Indicators of depression recurrence and early-life stress as predictors of the reciprocal relationship between negative affect (NA) and momentary rumination (MRSI-A) in daily life (EMA assessment) in formerly depressed participants (study 3). Standardized effects.

N of depressive episodes	B	SD	95% CI
μ NA	0.10	0.08	[-0.06, 0.25]
μ RUM	0.09	0.09	[-0.09, 0.26]
φ NA→NA	-0.11	0.10	[-0.31, 0.10]
φ RUM→RUM	-0.14	0.10	[-0.33, 0.06]
φ NA→RUM	-0.06	0.12	[-0.29, 0.17]
φ RUM→NA	-0.06	0.12	[-0.18, 0.29]
Age of depression onset	B	SD	95% CI
μ NA	0.05	0.08	[-0.10, 0.20]
μ RUM	0.05	0.07	[-0.10, 0.20]
φ NA→NA	0.04	0.09	[-0.14, 0.22]
φ RUM→RUM	0.15	0.10	[-0.05, 0.34]
φ NA→RUM	-0.06	0.12	[-0.29, 0.18]
φ RUM→NA	0.05	0.12	[-0.19, 0.30]
Residual symptoms	B	SD	95% CI
μ NA	0.00	0.08	[-0.15, 0.15]
μ RUM	-0.03	0.08	[-0.17, 0.12]
φ NA→NA	-0.09	0.09	[-0.26, 0.08]
φ RUM→RUM	-0.08	0.10	[-0.27, 0.11]
φ NA→RUM	0.23	0.12	[-0.01, 0.48]
φ RUM→NA	0.09	0.12	[-0.15, 0.32]

Cumulative early-life stress	B	SD	95% CI
μ NA	0.25*	0.08	[0.10, 0.39]
μ RUM	0.15*	0.07	[0.01, 0.39]
φ NA→NA	0.25	0.09	[0.07, 0.41]
φ RUM→RUM	-0.02	0.10	[-0.33, 0.07]
φ NA→RUM	0.27*	0.13	[0.03, 0.52]
φ RUM→NA	-0.01	0.13	[-0.35, 0.15]
History of physical, sexual, or emotional abuse	**B**	**SD**	**95% CI**
μ NA	0.09	0.08	[-0.07, 0.24]
μ RUM	0.14	0.07	[-0.03, 0.28]
φ NA→NA	0.15	0.09	[-0.02, 0.32]
φ RUM→RUM	-0.04	0.10	[-0.23, 0.17]
φ NA→RUM	0.25*	0.12	[0.02, 0.49]
φ RUM→NA	0.07	0.12	[-0.17, 0.31]
Stress severity	**B**	**SD**	**95% CI**
μ NA	0.25*	0.08	[0.10, 0.39]
μ RUM	0.17*	0.07	[0.03, 0.31]
φ NA→NA	0.29*	0.08	[0.12, 0.44]
φ RUM→RUM	-0.09	0.10	[-0.28, 0.11]
φ NA→RUM	0.12	0.11	[-0.10, 0.33]
φ RUM→NA	-0.05	0.12	[-0.30, 0.17]

HINT x *N* of depressive episodes	B	SD	95% CI
μ NA	0.17*	0.08	[0.01, 0.32]
μ RUM	0.02	0.08	[-0.13, 0.17]
φ NA→NA	0.12	0.09	[-0.06, 0.29]
φ RUM→RUM	0.09	0.11	[-0.12, 0.29]
φ NA→RUM	0.04	0.12	[-0.20, 0.27]
φ RUM→NA	0.10	0.12	[-0.15, 0.34]
HINT x Age of depression onset	B	SD	95% CI
μ NA	-0.02	0.08	[-0.17, 0.13]
μ RUM	0.06	0.08	[-0.09, 0.20]
φ NA→NA	-0.08	0.09	[-0.25, 0.10]
φ RUM→RUM	-0.13	0.09	[-0.31, 0.06]
φ NA→RUM	-0.04	0.12	[-0.27, 0.19]
φ RUM→NA	0.06	0.10	[-0.15, 0.27]
HINT x Residual symptoms	B	SD	95% CI
μ NA	-0.01	0.08	[-0.17, 0.15]
μ RUM	0.10	0.08	[-0.06, 0.25]
φ NA→NA	-0.02	0.09	[-0.21, 0.17]
φ RUM→RUM	-0.02	0.10	[-0.22, 0.18]
φ NA→RUM	0.09	0.14	[-0.18, 0.36]
φ RUM→NA	-0.11	0.12	[-0.35, 0.13]

HINT x Cumulative early-life stress	B	SD	95% CI
μ NA	0.07	0.08	[-0.08, 0.21]
μ RUM	-0.06	0.07	[-0.02, 0.08]
φ NA→NA	0.09	0.09	[-0.09, 0.26]
φ RUM→RUM	-0.03	0.10	[-0.22, 0.16]
φ NA→RUM	0.10	0.13	[-0.15, 0.36]
φ RUM→NA	0.09	0.12	[-0.14, 0.31]
HINT x History of physical, sexual, or emotional abuse	B	SD	95% CI
μ NA	-0.04	0.11	[-0.24, 0.19]
μ RUM	-0.03	0.11	[-0.23, 0.18]
φ NA→NA	0.04	0.13	[-0.20, 0.29]
φ RUM→RUM	0.02	0.14	[-0.26, 0.29]
φ NA→RUM	0.33*	0.15	[0.01, 0.60]
φ RUM→NA	0.23	0.15	[-0.09, 0.51]
HINT x Stress severity	B	SD	95% CI
μ NA	0.05	0.08	[-0.10, 0.20]
μ RUM	-0.06	0.07	[-0.20, 0.09]
φ NA→NA	0.05	0.09	[-0.12, 0.23]
φ RUM→RUM	-0.01	0.09	[-0.20, 0.18]
φ NA→RUM	-0.03	0.12	[-0.27, 0.21]
φ RUM→NA	0.11	0.11	[-0.11, 0.33]

4 Discussion

The purpose of the present thesis was to investigate whether rumination is a form of mood-reactive habitual thinking that entails a risk for depression, a widely held notion that has rarely been directly tested. It is noteworthy that no previous study has investigated this using a combination of self-report, experimental and real life in-the-moment measures of rumination, utilizing both depressed and never-depressed individuals, and thus adds to the relatively small number of studies in this area (Ólafsson et al., 2020; Van Vugt et al., 2018; Verplanken et al., 2007; Watkins & Baracaia, 2001). The results presented here provide insights into the presumed mood-reactive nature of rumination and suggest new answers to the question of what factors lead to habitual rumination. In the following section, the findings are discussed in light of their theoretical and clinical implications.

4.1 Trait Ruminative Brooding and Habitual Characteristics

The results of study 1 support the hypothesis that habitual characteristics of negative thinking are associated with the tendency to engage in ruminative brooding, but not ruminative reflection. Heightened self-reported ruminative brooding, but not ruminative reflection, was associated with greater habitual characteristics of negative thinking measured with the HINT (i.e., repetition, automaticity, lack of conscious awareness and intent, mental efficiency, and lack of control) in a non-selective student sample. This finding is in line with Hertel's (2004) conceptualization of depressive rumination as an automatic and involuntary habitual process. The findings are also consistent with previous research (Ólafsson et al., 2020; Verplanken et al., 2007) that also found rumination to be positively correlated with habitual characteristics. It also provides support for the habit account of rumination (Watkins & Nolen-Hoeksema, 2014), which states that when rumination is in the form of an analytical and abstract processing style (i.e., brooding), it is more likely to develop into a mental habit when compared to a more concrete and solution-focused way of thinking (i.e., ruminative reflection). Although there is conflicting evidence regarding the relative contribution of ruminative brooding and ruminative reflection to depression vulnerability (Joormann & Gotlib, 2010), the current findings hint at differential effects between the two forms of rumination, with only brooding showing an association with habitual negative thinking. These findings are in line with the suggestion that ruminative brooding, but not reflection, being habitually triggered (without awareness or

intent), making it difficult to control (Watkins & Nolen-Hoeksema, 2014), may confer increased risk for depression (Watkins & Roberts, 2020).

4.2 Experimental Rumination-Induction

Importantly, the association between ruminative brooding and habitual characteristics of negative thinking was also evident when rumination was experimentally induced in study 1. Rumination that has become habitual should be associated with more adverse consequences (Hertel, 2004; Watkins & Nolen-Hoeksema, 2014). It was therefore expected that habitual characteristics of negative thinking would predict increased persistence of NA and cognition in the rumination task. This was partially supported. Habitual characteristics of negative thinking predicted a greater persistence of dysphoric mood, indicating that rumination may be more detrimental when it's associated with habitual attributes. It is important to note that habitual characteristics of negative thinking added to the prediction of persistence of dysphoric mood on the rumination task, over and above what could be accounted for by the RRS alone – a well-established measure of depressive brooding. This underlines the possible additive value of considering habit-like automaticity of thoughts in the study of adverse consequences of ruminative thinking.

Contrary to predictions, habitual characteristics of negative thinking were not associated with a greater persistence of negative self-judgements following the rumination induction. Since participants are instructed to ruminate in the rumination-induction task (Nolen-Hoeksema & Morrow, 1993), it is possible that the task may not be optimally suited to capture the effects of habits because the instructions may draw attention to the habitual behaviour under question, reducing its effect (e.g., Spieler & Miltenberger, 2017). Future research should endeavour to elucidate this using experimental tasks that might better capture naturally occurring ruminative thoughts in response to negative mood, such as providing a subsequent no-task delay period that allows the opportunity for spontaneous rumination (e.g., Conway et al., 2000; Thomsen et al., 2004).

4.3 Mood-Reactivity of Depressive Rumination in Daily Life

To better investigate the supposed mood-reactivity of habitual rumination, and to address the limitations of study 1, EMA was utilized to capture the dynamic interplay between mood and rumination in the flow of daily life experiences. Study 2 found that momentary increased NA was prospectively associated with greater ruminative thinking at the next sampling occasion in individuals with a wide range of depression symptomology. This relationship was moderated by a measure of habitual characteristics of negative thinking, such that a stronger association was observed with greater levels of habitual characteristics (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness). Both of the hypotheses were therefore supported. These key findings replicate previous results (Blanke et al., 2021, Brose et al., 2015; Moberly & Watkins, 2008) and extend them by showing that NA can trigger ruminative thinking in everyday life as a function of habit.

These findings are in line with habitual accounts of depressive rumination (Watkins & Nolen-Hoeksema, 2014; Shaw et al., 2019; Watson & Roberts, 2020) which conceptualizes rumination as a response triggered by context (i.e., NA) rather than intentions or goals. More specifically, it is presumed that when people consistently rely on passive, negative and abstract ruminative thoughts to cope with discrepancies between desired states and their present reality, NA and ruminative thinking are paired over time, turning rumination into a habit that is triggered by context (i.e., NA) rather than goals or intentions. Because habitual characteristics specifically predicted the degree to which individuals ruminated in response to NA, and not just average levels of momentary rumination, this suggests that depression vulnerability may be in the form of rumination being habitually triggered by contextual factors (without conscious awareness and intent), making it difficult to control.

The results held when accounting for the shared variance of HINT with a cardinal measure of depressive brooding, indicating that HINT taps aspects of habitual rumination not fully captured by traditional trait measures of rumination. Although the brooding subscale of the RRS has often been considered a measure of habitual rumination, it focuses on the frequency of ruminative processing since respondents are asked to rate how often they have certain ruminative thoughts when they feel sad or depressed (rated on a scale of repetition from “almost never” to “almost always; Treynor et al., 2003). Although habitual behaviours occur often, frequency alone does not

mean that behaviour is habitual in itself (Verplanken, 2006; Wood & Rünger, 2016). Behaviour that is repeatedly performed in a stable context, may gradually become a habit, that is controlled by contextual cues, rather than mediated by goals or intentions. Thus, habitual behaviours are also characterized by a degree of automaticity (i.e., lack of conscious awareness and deliberate intent, mental efficiency, and lack of control; Neal & Wood, 2009). HINT is aimed to measure both the automaticity and repetition of negative thinking (Verplanken et al., 2007) and should therefore be associated with a measure of the context-response association between affect and rumination if it has become habitual. Consistent with this, study 2 found that HINT was a significant predictor of the temporal pairing between affect and rumination whereas the brooding subscale of the RRS was not. In contrast, HINT did not predict the degree to which rumination led to subsequent NA. Importantly, this pattern of findings was replicated in study 3. Overall, these findings underline the additive value of considering habit-like automaticity of thoughts in the study of adverse consequences of ruminative thinking in daily life.

According to the habit framework, rumination only develops into a trait-like habit once NA and ruminative thinking are paired over time. It is therefore theoretically consistent to expect some to ruminate without engaging in habitual negative thinking and vice versa (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Consistent with this, in study 2 there was significant variation in the degree to which habitual characteristics of negative thinking were associated with the context-response association between momentary affect and rumination.

Interestingly, although not specified by the habit-goal framework, the same pattern was found when assessing daily fluctuations in positive affect, showing that a deterioration of PA can also serve as a contextual trigger for ruminative thinking. Repeatedly experiencing *a decline* in PA whilst ruminating (e.g., when one's goals are persistently thwarted) might over time turn the deterioration of PA into trigger for subsequent rumination. Although this novel finding may suggest that the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) is relevant to a broader spectrum of emotional experiences, it should be interpreted with caution. Even though NA and PA are assumed to be independent constructs (Watson, Clark, & Tellegen, 1988), they are also strongly correlated (Green & Salovey, 1999). It may be that PA influences rumination partly through its overlap with change in NA. Using larger samples, it would be interesting to explore the relative contribution of negative and PA when investigating the habitual nature of

depressive rumination. Furthermore, it can be argued that this finding might to some extent reflect the effects of positive rumination (i.e., savoring; see Li et al., 2017) which has been found to be associated with heightened levels of PA. However, a momentary decline in PA (rather than increased levels) was associated with greater rumination, that was associated with lower average levels of PA during the experience sampling period, indicating adverse effects of ruminative brooding rather than savoring effects of positive rumination.

It is when rumination turns habitual that it is hypothesized to be more detrimental for people's emotional well-being (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Consistent with this, study 2 demonstrated that people ruminate in response to daily fluctuations in negative mood as a function of depressive symptom severity. This suggests that once rumination has become contingent on the emotional context (i.e., NA) people also tend to experience more severe symptoms of depression. Furthermore, when accounting for the shared variance of HINT with depressive symptoms, habitual thinking was no longer a significant predictor of the temporal pairing between NA and subsequent rumination. Although the possibility that this finding might to some extent reflect an overlap in negative content of the self-report measures cannot be excluded, it is also in line with theoretical accounts of habitual rumination and might suggest that the link between habitual thinking and the dynamic interplay of affect-rumination at the microlevel overlaps with depressive symptomology in a meaningful way (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Interestingly, this pattern did not emerge when looking at decreased PA as a trigger for everyday rumination. Habitual negative thinking remained a significant predictor even when accounting for depressive symptomology, suggesting that it may represent a less maladaptive form of ruminative process, consistent with dimensional approaches to psychopathology (Kozak & Cuthbert, 2016).

Habitual characteristics of negative thinking were not associated with emotional inertia (i.e., more carry over of mood from one moment to the next). Although not directly related, HINT was associated with the degree to which NA triggered subsequent rumination, which in turn was associated with greater levels of emotional inertia, as well as less carry-over of rumination from one moment to the next. Although speculative, it is possible that an indirect relationship exists wherein habitual attributes facilitate greater mood-linked rumination, which in turn leads to heightened emotional inertia. In comparison, ruminating in response to deteriorating PA did not involve the

same detrimental dynamic process of emotional inertia. This indicates that people recover relatively quickly when ruminating in response to decreased PA whereas when they ruminate in response to NA, they tend to get ´stuck´ in their current negative emotional state. The finding that greater NA-linked rumination was associated with reduced carry-over of rumination, suggests that once rumination has become contingent on negative mood, it tends to vary more over time. Indeed, previous research has found momentary rumination to vary considerably over time (Moberly & Watkins, 2008) and recent findings suggest that a greater history of depression may be associated with more variable levels of rumination (i.e., less carry-over; Bean et al., 2020). This is line with the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) which posits that once habitual, negative mood states induced by processes other than perceived goal discrepancy could trigger rumination (e.g., watching a sad movie), extending the range of situations that cue ruminative thinking.

4.3 Daily Mood-Reactive Rumination in People With- and Without Depression History

In study 3, measures of the dynamic interplay between NA and rumination in daily life revealed significant mood-related reactivity of rumination in recurrent formerly depressed participants, but not healthy controls. To our knowledge, this is the first explicit test of the mood-reactivity of depressive rumination using mobile EMA assessment in a clinical sample. These findings extend previous results from unselected samples (Blanke et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008) by showing that fluctuations in everyday NA may act as a trigger of subsequent ruminative thinking in euthymic individuals at high risk of experiencing depressive episodes. Importantly, these findings held when controlling for current depressive symptoms, in line with theoretical accounts of mood-reactive ruminative thinking as a potential vulnerability or risk marker (Watkins & Nolen-Hoeksema, 2014) and not just a concomitant of current depressive states (e.g., Ingram et al., 2011).

Like previous studies, a reciprocal relationship between NA and rumination was identified, with rumination predicting subsequent changes in NA, and NA predicting changes in rumination to the same effect. However, the current findings suggest that mood-reactive rumination might be limited to individuals at-risk for depression. This does not necessarily contradict previous findings. Indeed, the few existent studies (Blanke et al., 2021,

Hjartarson et al., 2021, Moberly & Watkins, 2008) were limited to student samples including individuals with a wide range of depressive symptoms and recruited both those who were and were not prone to depression. Furthermore, the mood-reactivity of rumination was found to be moderated (Moberly & Watkins, 2008) and fully accounted for by current depressive symptomatology (see also results of study 2; Hjartarson et al., 2021). In line with this, the healthy control group utilized in the study 3, which did not have any diagnosable history of depression or other mental disorders, did not demonstrate such mood-reactivity of rumination in daily life. Together these findings suggest that mood-reactive rumination varies according to the depression-risk spectrum in line with theoretical accounts of depressive rumination (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020) and highlights the need to take differing levels of depression risk into account in future studies on mood-reactive rumination.

In line with the second hypothesis, study 3 found that micro-level shifts in mood-reactive ruminative thinking were associated with the perceptions of one's negative self-focused thoughts being automatically triggered without intention and control (HINT). This replicates the results from study 2 (Hjartarson et al., 2021) and is consistent with recent conceptualisations of depressive rumination as a response triggered by context (i.e., downward shifts in mood) rather than goals or intentions (Farb et al, 2015; Watkins & Nolen-Hoeksema, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). Since mood-reactive rumination was only evident in at-risk individuals, and habitual characteristics specifically predicted the strength of the reactivity, this suggests that depression risk may be in the form of rumination being triggered with a high degree of automaticity in response to daily fluctuations in NA, making it difficult to control.

The emphasis that habitual accounts place on the automaticity of ruminative thinking is novel given that traditional instruments that assess rumination only measure the frequency of ruminative thinking in response to negative mood (Treynor et al., 2003; Watkins & Roberts, 2020). HINT (but not brooding) was a significant predictor of the temporal pairing of NA and subsequent rumination whereas it did not predict the dynamic pairing between rumination and subsequent NA. Thus, the impact of rumination on affect was not associated with habitual characteristics, further highlighting the specificity of the current findings. Importantly, HINT remained a unique predictor of mood-reactive rumination when controlling for trait levels of brooding and current depressive symptoms. This suggests that HINT assesses aspects of mood-reactive rumination not fully captured by

traditional trait measures of rumination and which cannot be explained by confounds with current depression status or overlap in negative content of the self-report measures. Thus, we may need to go beyond frequency to tap depression risk and concentrate on reactivity and automaticity, in addition to trait or mean levels of rumination.

4.4 Potential Moderators of Rumination As-A-Habit

There is limited research into the specific factors that might contribute to transient episodes of rumination becoming a mood-reactive habit in the first place. Recent theoretical accounts broadly specify person-specific factors that contribute to a lack of flexible responding (i.e., restricted coping repertoire, cognitive inflexibility) and situational factors that thwart important goals (i.e., chronic stress and abuse) as potential risk factors for rumination to consolidate into a habitual style of thinking (e.g., Nolen-Hoeksema & Watson, 2014). The current thesis explored whether depressive rumination was related to several potential moderators.

It has been suggested that depression might be related to a more general tendency towards habitual responding (Byrne et al., 2021; Ólafsson et al., 2019) which might predispose people to develop rumination as a habit. However, the relationship between depressive rumination and habit-acquisition remains an under-explored area of research. In study 1, trait ruminative brooding, but not ruminative reflection, was associated with greater habitual responding in everyday life on the Creature of Habit Scale, a self-report measure of habitual propensity. This is in line with previous research which has linked depression and habit-driven behaviours (Byrne et al., 2021). Rumination, however, was not associated with a greater tendency towards habit-directed behaviour control on an outcome-devaluation task – suggesting that although rumination might be associated with a general tendency towards habitual behaviours in everyday life, it is not associated with an imbalance in habit vs goal-directed learning, as assessed with the FFG. These results of study 1 should be interpreted with caution given the unselected sample included as well as the correlational nature of these findings. Future research should strive to replicate the current results in addition to explore whether a greater tendency towards habit-directed behaviour control intereacts with other potential backround factors, such as problems in excecutive control and early-life stress, in predicting a greater ruminative disposition.

In study 3, depression course (number of episodes, age of onset, and stability of remission) was not associated with mood-reactive rumination in daily life. This could reflect the homogeneity of the sample used, consisting of high-risk individuals with at least three-lifetime depressive episodes, excluding the lower end of vulnerability and potentially inhibiting the ability to detect these effects (cf. Buckman et al., 2018), but may also indicate a mechanism independent of the depression course, that constitutes a risk or vulnerability on its own (Shaw et al., 2019). Consistent with this view, we found that formerly depressed individuals with a history of physical, sexual, or emotional abuse before the age of 17, demonstrated greater levels of mood-reactive rumination. Furthermore, habitual characteristics (HINT) predicted stronger mood-reactive rumination in the formerly depressed reporting physical, sexual, or emotional abuse but not in those without such a history. Prior findings show that rumination is associated with a history of early-life stress and abuse (LeMoult et al., 2020) and recent habitual accounts of rumination suggest that stressful and abusive environments may constrain peoples' emotional coping repertoire, consolidating rumination as a mental habit when paired with negative mood over time (Shaw et al., 2019; Watkins & Roberts, 2020). Evidence suggests that stressful early-life events play a role in internalizing psychopathology through sensitization processes (McLaughlin et al., 2019) and reduced cognitive control (Jenness et al., 2020) that may pave the way for habit formation (e.g., Gordon et al., 2020).

4.5 Clinical Implications

The findings of this thesis could have significant clinical implications. They provide a direct test of the habitual model of rumination that has not been tested empirically so far and reveal a potential vulnerability marker that could constitute an important mechanism of change during therapy. Rumination that is triggered with a high degree of automaticity might make it difficult for some people to fully recover from depression. Elevated rumination has been found to predict poorer outcomes following standard cognitive-behavioural therapy (Kertz et al., 2015). Given that rumination has become contingent on the emotional context (i.e., negative or positive affect), preventive and acute therapy of depression needs to target the context-response association between affect and rumination, not just the *content* of the ruminative thoughts. The ruminative response needs to be replaced with a more helpful way of responding (e.g. concrete thinking, mindfulness, relaxation) to develop

new context-response associations (Watkins & Nolen-Hoeksema, 2014; Wood & Neal, 2007).

This is in line with the recent development of interventions specifically designed to target the habitual qualities of rumination, such as rumination-focused CBT (Watkins, 2018) and mindfulness-based cognitive therapy (MBCT; Segal et al., 2018) where the ruminative response is specifically replaced with more helpful ways of responding (e.g., concrete thinking, compassion, mindfulness). Although rumination-focused interventions have found outcome effects that compare favourable to standard CBT (Hvenegaard et al., 2020; Teismann et al., 2014; Watkins et al., 2011) it remains to be seen whether they lead to greater reductions in rumination compared to other established treatments (Spinhoven et al., 2018).

The experimental and EMA measurement strategies used in the current thesis are ideally suited to test whether interventions are successful in reducing the mood-reactive automaticity of ruminative thinking and to study mechanisms of change during therapy. Furthermore, the current findings suggest that rumination-focused interventions may be highly prescriptive for those with a history of childhood abuse. This is consistent with previous findings that MBCT provides additional protection over treatment-as-usual or placebo but only for those with a history of childhood abuse or adversity (Williams et al., 2014).

4.6 Strengths and limitations

4.6.1 Strengths

To our knowledge, the current thesis is the first explicit test of habit-account of depressive rumination, using a combination of self-report, experimental and EMA assessment of depressive rumination. These key findings replicate previous results (Brose et al., 2015; Moberly & Watkins, 2008; Ólafsson et al., 2020) and extend them by showing that NA can trigger ruminative thinking in everyday life as a function of habit and that it varies according to the depression-risk spectrum in line with theoretical accounts of depressive rumination (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020). Furthermore, a particular strength of the current studies was the use of EMA assessment to capture the dynamic interplay between rumination and affect in the flow of peoples' daily life experiences. This

allowed us to test the effect of habitual characteristics on the temporal relationships between rumination and affect in an ecologically valid way (Myin-Germeys, 2018), which addresses limitations of previous studies (Ólafsson et al., 2020; Verplanken et al., 2007) restricted to trait measures of rumination. Crucially, we revealed a dynamic interaction between rumination and affect that would not have been apparent using trait measures alone. Most importantly, unlike all other previous studies, the current thesis present the first investigation into mood-reactive rumination using a clinical sample that consisted of recurrent formerly depressed individuals at risk for future episodes. This allowed us to compare at-risk individuals to those without any history of depression at all and provide much needed data on the clinical relevance of habit account of rumination.

4.6.2 Limitations

The findings of the current thesis should also be interpreted in light of several limitations. Some are general across all studies whereas others are specific to the particular study in question.

Across all studies the majority of the samples were female, which might preclude the generalization of the findings to males. Another limitation has to do with the inference of causality. Although we found affect to influence rumination across time as a function of habit, and the intensive longitudinal EMA methodology provided an inference of temporal causality, it does not preclude other causal influences. Effect sizes across all studies were generally moderate to small, indicating that other contributing factors might also cause affect to evoke a subsequent ruminative response.

Furthermore, there exist yet no reliable behavioural proxies to measure rumination as-a-habit. Across all studies, habitual characteristics were inferred from self-report. This highlights the need for the development of more specific behavioural measure of habitual rumination to clarify the unique role of habit in depressive rumination, while the research base of existing measure is expanded and their link with related constructs explored (e.g., metacognitive beliefs).

Although it was tested whether habitual characteristics influenced the strength of the temporal relationship between affect and rumination, the current studies do not address the developmental aspect of how rumination becomes habitual in the first place. According to the habit account (Watkins &

Nolen-Hoeksema, 2014) situational factors that systematically thwart important goals and contribute to low mood (i.e., chronic stress and abuse) and person-specific factors associated with a lack of flexible responding (i.e., restricted coping repertoire and cognitive inflexibility) are hypothesized to facilitate the formation of rumination as a habit. Future research should aim to elucidate whether such situational and person-specific factors govern the strength the habitual association between affect and rumination.

It must also be noted that in studies 2 and 3 participants were specifically instructed to answer EMA questions in the moment based on how they felt just prior to the alert, the order in which EMA questions were presented was fixed. Items pertaining to affect were presented first preceding the rumination items, which could potentially prime a response for the rumination questions. Future research should address this potential shortcoming by utilizing varied or randomized item order designs. Similarly, the EMA rumination items are presented in an emotionally neutral way (e.g., „Right now, I wonder why I react the way I do“) which raises the question to what degree the current findings generalize to other well known measures of momentary rumination with negatively valenced items, such as items on the The Brief State Rumination Inventory (e.g., Right now, I wonder why I can´t respond in a better way). The generalizability of the current findings can be assessed by replicating the current findings using other well established measures of momentary rumination.

Furthermore, although the current investigation identified the automaticity of mood-reactive rumination at the level of short-term dynamics as a potential risk factor, it remains to be tested whether it *predicts* depression onset and relapse using prospective designs and *under what conditions* it results in such emotional cascades (e.g., at times of heightened and persistent NA). Also, formerly depressed participants were required to have at least three previous episodes, in line with criteria used in studies of MBCT in recurrent depression (e.g., Williams et al., 2014). Although supporting our aim to study mood-reactive rumination in a group at high-risk of depression, this requirement precludes conclusions being drawn regarding people with fewer episodes. Although formerly depressed participants were in a euthymic state, as defined by not meeting diagnostic criteria for major depressive episode and having scores below established cut-off on measure of depressive symptoms, they had elevated mean levels of daily NA during the EMA. However, controlling for depressive symptoms did not change the pattern in the findings, providing reassurance that our results are not confounded with current depressive states during the assessment period.

4.7 Conclusions

Negative affect can trigger ruminative thinking as a function of habit consistent with recent theoretical frameworks of depression vulnerability (Watkins & Roberts, 2020). Habitual characteristics appear to be specifically associated with the maladaptive component of ruminative brooding but not ruminative reflection, a more adaptive form of rumination.

The results of the current thesis demonstrate that ecological momentary assessment may be a valuable measurement paradigm to test predictions derived from habit-accounts of depressive rumination. Mood-reactive rumination may be a potential vulnerability marker for depression, with rumination being habitually triggered in response to momentary fluctuations in NA with a high degree of automaticity, and with a deleterious effect on mood. Mood-reactive rumination varies according to the depression-risk spectrum and is specific to high-risk individuals with a recurrent history of depression as compared to healthy never-depressed individuals. The current thesis suggests ways how depression vulnerability may emerge as a dynamic relationship between NA and rumination across time, not captured by traditional trait measures of rumination frequency.

Rumination may be more detrimental when habitual because it leads to a greater persistence of dysphoric mood (i.e., emotional inertia) and more fluctuating levels of ruminative responding. To our knowledge, this is the first investigation into the role of habitual characteristics in the dynamic interplay between rumination and affect using a combination of self-report, experimental and daily-life EMA methodology. Habitual rumination may constitute a risk independent of the depressive course and originate in early-life stress and abuse; however, it is still unclear whether it is related to a more general tendency towards habitual behaviours in everyday life.

Collectively, these findings highlight the potential role of habit rumination in depression vulnerability. They underscore the importance of exploring new ways to measure potential risk factors for depression to expand the current evidence base and in order to gain new insights into the treatment of major depression.

4.8 Future directions

The current investigation identified the automaticity of mood-reactive rumination as a potential risk factor for depression. However, it remains to be tested whether it *causes* depression. Studies using longitudinal and prospective designs should strive to confirm that mood-reactive rumination both precedes and predicts depression onset and relapse. Similarly, even though mood-reactive rumination was associated with a history of early-life stress, the study does not address how rumination develops as-a-habit in the first place. Other potential catalysts for rumination to consolidate as a mood-reactive habit have been suggested, such as cognitive inflexibility (Watkins & Nolen-Hoeksema, 2014), difficulties with attentional disengagement (Koster et al, 2011), and an imbalance in habit vs goal-directed behaviour control (Ólafsson et al., 2020). Future research should strive to assess if the strength of the habitual association between NA and rumination changes longitudinally as a function of these potential moderators. The EMA assessment methodology utilized in the current study is ideally suited to test these novel predictions.

Future research could expand on the current findings by exploring whether targeting the mood-reactive automaticity of rumination as a mechanism of change during therapy can inform more personalized treatment selection and thereby reducing suffering and burden of depression. Promising interventions include cognitive bias modification (CBM; Hertel et al., 2014) and rumination-focused CBT (Watkins, 2018), that involve repeated training of alternative adaptive responses when faced with emotionally challenging situations. We hypothesize that individuals with greater habitual rumination should respond more favorably to interventions such as CBM and rumination-focused CBT compared to individuals with less habitual rumination. Importantly, the EMA measurement strategy utilized in the current study could be used to test whether interventions are successful in reducing the habitual characteristics of the association between affect and rumination. This may provide information on the mechanisms of change during therapy and the predictive value of utilizing EMA measurement approaches in studying psychological well-being (see e.g., Dejonckheere et al, 2019). The present findings also raise the question to what extent the habit framwork applies to other forms of abstract negative repetetive thinking, such as worry and self-criticism, that share similarities and conceptual overlap with ruminatio (Watkins, 2008). New insights might be gleaned from testing the specificity of the findings to depressive rumination and if other related constructs also present as a mood-reactive habitual phenomena.

To date, no reliable behavioural proxies to measure rumination as-a-habit exists, and was therefore inferred from self-report in the current investigation. Future studies on the subject should also strive to use more specific behavioural measures of habitual rumination. A promising first step would be to develop EMA measures of momentary habitual responding, for instance by adapting the habit index of negative thoughts (HINT) or self-report habit index (SRHI; Verplanken & Orbell, 2003). It might also be possible to measure the automaticity of habitual rumination using neurophysiological measures. A central finding in behavioural neuroscience is that habit performance is mediated by distinct *cortico-basal ganglia networks* and related to the activiation of the *lateral putamen* (Patterson & Knowlton, 2018; Yin & Knowlton, 2006). The current findings might be replicated using a rumination-induction procedure in combination with neuroimaging. It could be tested whether greater mood-reactive rumination is associated with a heightened activation of the habit neural system, and providing a direct test of the validity of self-report measures as a proxy for measuring habitual rumination.

Future studies on depressive rumination might inform and improve the current EMA methodology by incorporating analyses of the time scale over which mood cues a subsequent ruminative response. Current theoretical accounts of habitual rumination (e.g., Watkins & Nolen-Hoeksema, 2014) are vague regarding the specific time that should elapse between mood and the subsequent ruminative response. It is well established that the estimation of lagged effects change depending on the time elapsed between measurement waves (e.g., minutes vs hours or 1 hour vs 2 hours etc.; Kuiper & Ryan, 2018). Furthermore, it is an established fact that habitual context-response associations depend on the nature of the contextual cue (e.g., specific environments vs internal experiences) and there is evidence that the time scales of habitual behaviours might also differ between individuals (Garder et al., 2022). As evidence from EMA studies accrues it could become possible to estimate these specific time scales using recent developments in continious-time modelling (see e.g., Kuiper & Ryan, 2020). Such an approach might provide important insights into the specific temporal interval of mood-reactive rumination, at what time interval it is strongest, and whether the time scale depends on meaningful person-specific differences.

Finally, future studies should strive to implement measures that go beyond rumination frequency. The findings of the current thesis suggest that traditional measures of trait rumination might not be enough to capture mood-reactive rumination. This is in line with recent guidelines which recommend

that behaviour frequency should not be used on its own to infer the strength of habits (Gardner et al., 2022). Thus, we may need to go beyond frequency to better capture depression risk. This suggest that future studies should concentrate on reactivity and automaticity, in addition to trait or mean levels of rumination. This might be accomplished by including self-report measures of habitual characteristics (e.g., the HINT) or more sophisticated EMA measures of the context-response between mood and ruminative thinking, as demonstrated in the current thesis. Given the speed at which technology advances and increased availability of web-based solutions, measures of the complex dynamics of rumination in the flow of everyday life experiences might yield important insights into the nature of depressive rumination and depression vulnerability more generally.

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Papers

Paper I

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An experimental test of the habit-goal framework: Depressive rumination is associated with heightened habitual characteristics of negative thinking but not habit-directed behavior control

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Abstract

Habitual thinking may underpin a heightened disposition to engage in rumination in response to negative mood, a widely held notion that has rarely been directly tested. The purpose of the current study was to investigate whether rumination is associated with habitual attributes and whether it is related to an imbalance in habit relative to goal-directed behavior control. University students (N=115) completed self-report questionnaires, a rumination induction paradigm and an outcome devaluation task that measures habitual vs goal-directed behavior control. Greater habitual characteristics of negative thinking (e.g., automaticity, lack of conscious awareness, control, and intent) were associated with ruminative brooding but not ruminative reflection and predicted more persistent dysphoric mood following rumination induction. Rumination was not, however, consistently associated with an imbalance in habit versus goal-directed behavior control. These findings indicate that depression vulnerability may be in the form of rumination being habitually triggered (without

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awareness or intent) with deleterious effects on mood. Although habitual, rumination may not be related to an imbalance in habit relative to goal-directed behavior control. These findings provide support for current theoretical accounts of rumination and set important boundary conditions in the search for specific factors that contribute to rumination as a habit.

Keywords
Cognitive vulnerability, depression, habit, rumination

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When bad things happen in life, most people feel down or mildly depressed, at least occasionally. For most individuals, such negative mood states are fleeting and relatively short-lived. For others, however, negative mood lingers and becomes progressively more severe over time. The severity of such negative emotional reactions is predicted by the degree to which people tend to engage in rumination in response to their negative mood. Rumination is a form of negative thinking that involves repetitively and passively dwelling on the causes, meanings, and consequences of one's feelings and distress (Nolen-Hoeksema, 1991). Thus, to understand individual differences in depression vulnerability, it becomes necessary to delineate the causal processes that lead to a ruminative disposition.

Ample evidence supports rumination as a vulnerability marker for the development and maintenance of depressive symptoms and episodes (Nolen-Hoeksema et al., 2008; Watkins, 2008). Prospective longitudinal studies using the Ruminative Responses Scale (RRS; Nolen-Hoeksema & Morrow, 1991) have found that people who tend to ruminate in response to negative mood are more likely to develop depressive disorders and experience more persistent periods of dysphoric mood than low ruminating individuals (Just & Alloy, 1997; Nolen-Hoeksema, 2000; Spasojevic & Alloy, 2001). Experimental studies using the rumination induction procedure developed by Nolen-Hoeksema and Morrow (1993) have found that rumination leads to heightened and prolonged negative affect and cognition in both dysphoric (Nolen-Hoeksema & Morrow, 1993) and clinically depressed individuals (Donaldson & Lam, 2004; Lavender & Watkins, 2004). Rumination induction also results in greater persistence of negative mood in non-dysphoric participants when first induced into a negative mood state (e.g., Burkhouse et al., 2017; Ciesla & Roberts, 2007; Joormann & Siemer, 2004).

Depression appears to be specifically characterized by high levels of ruminative brooding (Joormann et al., 2006), a subtype of rumination that involves passively focusing on symptoms of one's distress and the possible meaning and implications of those symptoms (Treynor et al., 2003). In contrast, ruminative reflection, which consists of active cognitive problem-solving that may improve one's mood, has traditionally been thought less associated with depression (e.g., Burwell & Shirk, 2007). Brooding is thought to involve a more self-critical, evaluative, and judgmental type of self-focus that leads to a greater persistence of negative mood (Rude et al., 2007). However, ruminative reflection is elevated in both currently and formerly depressed samples (Joormann & Gotlib, 2010), which suggests that adaptive self-reflection may turn into maladaptive brooding, when individuals attempting to understand their problems repeatedly fail to come up with solutions (Takano et al., 2011).

Rumination as a mental habit

Habitual thinking may explain why some people respond to negative affect with a ruminative response style. According to the Response Styles Theory, rumination is an enduring, stable, and habitual-like tendency (Nolen-Hoeksema et al., 2008). This is consistent with Hertel's (2004) conceptualization of rumination as a habit of thought that is automatic and often involuntary. More recently, Watkins and Nolen-Hoeksema (2014) proposed a habit-goal framework of depressive rumination, where rumination is seen as a mental habit that is initiated without awareness or conscious intent in response to negative mood. Habits are formed by learned associations between responses and their performance contexts. Once formed, context cues become automatic triggers for the behavior, such that it is controlled solely by the presence of the context cue, rather than individual's goals or motivations (Triandis, 1977; Wood & Neal, 2007). Habitual accounts of rumination therefore differ from other conceptualizations of repetitive

behaviors (e.g., the perseverative cognition hypothesis; Brosschot et al., 2006) in that rumination is seen as a stimulus-triggered response that persists despite changes in outcome value.

According to the habit-goal framework, transient episodes of goal-directed ruminative thoughts arise in response to a perceived discrepancy between one's goals and the status of progress toward these goals (Watkins & Nolen-Hoeksema, 2014). The process can be considered adaptive when the repetitive thinking helps to reach goals. However, when goals are repeatedly not reached, ruminative thoughts may persist (Martin & Tesser, 1996; Watkins, 2008). Because unresolved goal conflict leads to increased negative affect, episodes of goal-directed rumination may develop into a mood-linked habit over time when it repeatedly occurs contingent on the same context (i.e., negative mood). Both situational factors that systematically thwart important goals and are associated with low mood (i.e., chronic stress, emotional, physical, or sexual abuse and neglect) and person-specific factors that contribute to a lack of flexible responding (i.e., restricted coping repertoire and cognitive inflexibility) should facilitate the formation of rumination as a habit (Watkins & Nolen-Hoeksema, 2014). Analytical and abstract depressive brooding is more likely to develop into a mental habit compared to ruminative reflection, a more flexible and concrete way of thinking. According to the framework, brooding leads to the recurrent pairing of negative mood with ruminative thoughts which develops into a mood-driven habit over time, whereas reflection is not assumed to play such a role (Watkins & Nolen-Hoeksema, 2014). Nonetheless, given the inconclusive evidence regarding a clear distinction between ruminative brooding and reflection, this is an assumption that remains to be tested.

Consistent with the habit-goal framework, rumination has often been described as being habitual in the depression literature (e.g., see Hertel, 2004), however, this has rarely been directly tested. Habits are automatic in the sense that they are initiated without conscious awareness, intent, or effort and are therefore difficult to control (Verplanken et al., 2007). Indeed, Watkins and Baracaia (2001) found that self-identified ruminators reported that rumination occurs without conscious intent and is difficult to control. Furthermore, recent theoretical conceptualizations of depression vulnerability have characterized rumination, in some way or another, as a mental habit that traps the individual in a vicious cycle of greater attentional fixation on and processing of negative information (e.g., Farb et al., 2015; Koster et al., 2011). A study by Verplanken et al. (2007) found in a sample of university students that rumination was associated with self-reported lack of conscious awareness, lack of deliberate intent, and greater difficulties in controlling negative thinking. Notably, greater self-reported habitual characteristic of negative thinking prospectively predicted additional variance in future depression, above measures of negative content of thought alone (Verplanken et al., 2007). Van Vugt et al. (2018) showed, in a novel simulation study, that modeling rumination as a habit best predicted the impairments of depressed participants on a sustained attention task, concluding that rumination might be caused by maladaptive habits of thought. More recently, a study by Ólafsson et al. (2020) found that ruminative brooding, but not reflection, was associated with heightened self-reported habitual attributes measured with the Self-Report Habit Index (Verplanken & Orbell, 2003).

Thus, there exists preliminary evidence for the notion of rumination as a mental habit. However, the existent findings do not address some of the key assumptions of the habit-goal framework. At present, little research is available on whether depressive brooding, but not ruminative reflection, is associated with habitual attributes and, importantly, it remains to be directly tested whether heightened habitual characteristics are associated with greater detrimental effects of rumination.

Habitual and goal-directed behavior control

There is limited research into the specific factors that might contribute to rumination becoming habitual in the first place. The habit-goal framework broadly defines personal and environmental factors that lead to inflexible responding as possible mechanisms (Watkins & Nolen-Hoeksema, 2014). Similarly, Hertel's (2004) earlier conceptualization suggested that external factors that impair guided attention (e.g., impairments in working memory and sustained attention) could contribute to the formation of habitual rumination. A more recent model by Shaw et al. (2019) proposes that certain risk factors (e.g., stressful environments, temperament, genetic vulnerability, and parenting styles) contribute to higher levels of negative affect, which in turn may perpetuate state levels of rumination. Over time, this repeated coupling with negative affect may consolidate rumination

into a habitual trait-like response style, especially among those with cognitive control deficits.

There is growing evidence that there are individual differences in the propensity to form habits, with greater habit propensity implicated in disorders such as addiction, eating disorders, and obsessive-compulsive disorder (De Wit, 2017). More specifically, research has shown behaviors to be guided by distinct but interrelated habit and goal-directed control systems, presumably underpinned by different biological brain systems. Goal-directed control is implicated in the adjustment of behavior based on predictions of future outcomes, whereas habitual control is driven primarily by experiences of past outcomes (Dolan & Dayan, 2013). Impairments in goal-directed control (e.g., at times of stress and increased working memory load) might contribute to faster and stronger formation of habit because of greater reliance on habit-directed behavior control (Linnebank et al., 2018).

Individual differences in habit versus goal-directed behavioral control have been studied with a computerized outcome devaluation task that taps people's ability to alter behavior when outcome value changes. In this experimental paradigm (De Wit, 2017), previously trained responses that resulted in valued outcomes (i.e., were reinforced) lose their value as the outcome becomes devalued. Repeating previously reinforced but currently devalued responses (i.e., slips-of-action) can be taken as a persistence of previous goal-directed behavior that has become habitual through overtraining, and insensitive to outcome value (De Wit, 2017; Linnebank et al., 2018). Self-report measures such as the Creature of Habit Scale (COHS; Ersche et al., 2017) have also been utilized to study individual differences in habit proneness, and shows that experiences of adversity during childhood — a well-known risk factor for depression (Nelson et al., 2017), is associated with increased automatic habitual responding in everyday life.. A study by Ólafsson et al. (2020) found that on an outcome devaluation task, stronger habit relative to goal-directed behavior control was associated with a greater number of previous depressive episodes in a group of formerly depressed individuals. Moreover, Heller et al. (2018) found that on a two-stage decision-making task, individuals high in depression demonstrated greater habitual and less goal-directed decision-making in the face of stress.

Thus, depression may be associated with difficulties modulating behaviors in service of goals, making people more prone to habitual responding. Consistent with this, depression is strongly associated with stressful life events (Hammen, 2005; Monroe & Cummins, 2017) and more chronic forms of stress and early adversities (Nelson et al., 2017), that can impair the ability to use effortful and goal-directed behavioral control (Beevers, 2005; Snyder, 2013), which may make people more prone to habitual responding (Schwabe & Wolf, 2009; Wood & Ruünger, 2016). A novel prediction is that an imbalance between the habit and goal-directed control strategies might predispose people to develop rumination as a habit, especially when faced with a frequent lack of progress toward goals and a lack of flexible responding (Watkins & Nolen-Hoeksema, 2014).

Aim of the present study

The aim of the present study was to empirically test the notion that rumination is a form of mental habit. Given the pivotal role rumination plays in the etiology of depressive affect, identifying the cognitive factors that contribute to a ruminative disposition is of vital importance (Nolen-Hoeksema et al., 2008; Southworth et al., 2017).

Although there exists preliminary evidence for the notion of rumination as a mental habit, the existent findings do not address some of the key assumptions of the habit-goal framework. Little research is available on whether depressive brooding, but not ruminative reflection, is associated with habitual attributes and, importantly, it remains to be directly tested whether heightened habitual characteristics are associated with greater detrimental effects of rumination. We also explore to what extent ruminative brooding may be related to more general difficulties in modulating behaviors in service of goals, that can make people more prone to forming habits. In the present study, we investigate this using a combination of both self-report measures and experimental tasks.

First, consistent with the habit-goal framework of rumination (Watkins & Nolen-Hoeksema, 2014) we expected greater self-reported habitual characteristics of negative thinking (i.e., repetition, lack of conscious awareness and intent, mental efficiency, lack of control, and self-descriptiveness) to be associated with increased ruminative brooding but not ruminative reflection. Second, to expand on this, we also utilized a rumination induction task to assess brooding-like rumination in an experimental setting. Rumination that has become habitual should be associated with

more adverse consequences (Hertel, 2004; Watkins & Nolen-Hoeksema, 2014). It was therefore expected that habitual characteristics of negative thinking would predict a greater persistence of negative affect and cognition following induction of ruminative brooding.

Finally, because depression may be associated with difficulties modulating behaviors in service of goals, we investigated whether rumination, as indexed by both self-report and experimental induction, is associated with greater habitual responding, measured with a questionnaire of habit propensity in everyday life and an experimental outcome devaluation task. We expected rumination to be associated with greater self-reported daily habits and greater slips-of-action on the outcome devaluation task.

Method

Participants

Participants were 115 students (27 males, 88 females) between the age of 19 and 56 years ($M = 23.8$; $SD = 4.4$) who responded to an introductory e-mail sent out to all registered students at the University of Iceland. Inclusion criteria were an age between 18 and 65 years and having a good command of both spoken and written Icelandic. Informed consent was obtained from all participants. All participants were volunteers but received a financial compensation for their participation (value: 4,000 ISK, approximately US$30).

Materials

Self-report measures

Demographic information. Participants completed a self-report demographic form inquiring about their age, gender, marital status, and level of education.

Psychiatric symptoms. Depressive symptoms were assessed with the Beck Depression Inventory-II (BDI-II; Beck & Steer, 1990), a 21-item self-report questionnaire. Items are rated on a 4-point scale ranging from 0 to 3, with a maximum total score of 63. Higher scores indicate increased symptom severity. The Icelandic version of the BDI-II (Arnarson et al., 2008) has shown good psychometric properties.

Ruminative Responses Scale. The RRS (Nolen-Hoeksema & Morrow, 1991; Treynor et al., 2003) is a self-report measure of ruminative disposition. The RRS consists of 22 items that require participants to indicate the extent to which they engage in particular ruminative responses when in a negative mood. Items are rated on a 4-point Likert-type scale ranging from "never or almost never" to "always or almost always." Factor analysis has found the RRS to yield two 5-item subscales; of passive, analytical, and maladaptive (brooding) and more active and adaptive (reflection) forms of ruminative thinking. The Icelandic version has good psychometric properties (Pálsdóttir & Pálsdóttir, 2008).

Habit Index of Negative Thinking. The habitual quality of negative self-thinking was measured with the Habit Index of Negative Thinking (HINT; Verplanken et al., 2007). The HINT is a 12-item self-report scale that measures the degree to which negative self-thoughts occur frequently, are initiated without awareness, are unintended, are difficult to control, and are self-descriptive. Each item is rated on a 7-point scale in response to the general prompt, "Thinking negatively about myself is something . . . ," and included items such as "I do unintentionally" and "I start doing before I realize I'm doing it." The HINT thus taps the process aspects—the repetitive and automatic nature of the thoughts—which are considered as key elements of mental habits and which can be distinguished from the content and valance of the thoughts themselves (e.g., Verplanken et al., 2007; Watkins, 2008). The Icelandic version of the HINT has high internal consistency and good discriminant validity (Jóhannesdóttir & Jóhannesdóttir, 2019).

The Creature of Habit Scale. The COHS (Ersche et al., 2017) was used to assess individual differences in participants' propensity to habits in everyday life. The COHS is a 27-item self-report questionnaire that assesses two aspects of habitual responding, routine and automaticity, in a variety of domains. Items were rated on a 5-point scale ranging from "strongly disagree" to "strongly agree" and included items such as "whenever I go into the kitchen, I typically look in the fridge" and "I often find myself running on autopilot." The Icelandic version of the COHS has good psychometric properties (Jóhannesdóttir & Jóhannesdóttir, 2019).

Experimental measure of ruminative disposition. Rumination was also assessed using a standard rumination induction task (Nolen-Hoeksema & Morrow, 1993). The task was modified to include a negative mood manipulation to facilitate the emergence of ruminative processing (e.g., see Burkhouse et al., 2017;

Ciesla & Roberts, 2007; Joormann & Siemer, 2004). Measures of mood and negative self-judgments were collected with visual analog scales (VAS) throughout the task.

Mood manipulation. All participants listened to an 8-min musical excerpt from Prokofiev's "Russia Under the Mongolian Yoke," remastered at half speed, while thinking about a sad autobiographical event from their life. This combination of music and autobiographical recall has been found to be effective in inducing a transient dysphoric mood in previous research (Jarrett et al., 2012; Lau et al., 2004; Martin, 1990).

Rumination induction. Participants were then instructed to engage in a ruminative cognitive task developed by Nolen-Hoeksema and Morrow (1993), which has been used extensively in prior experimental research to induce an analytical and brooding thinking style (see Nolen-Hoeksema et al., 2008; Rimes & Watkins, 2005). Participants focused on the meaning, consequences, and causes of their current feelings for 8 min when reading 28 prompts adapted from Nolen-Hoeksema and Morrow (1993). They were instructed to "for the next few minutes, try your best to focus your attention on each of the ideas on the following pages. Read each item slowly and silently to yourself. As you read the items, use your imagination and concentration to think about the causes, meanings and consequences of the items. Spend a few moments visualizing and concentrating on each item, attempting to make sense of and understand the issues raised by each item." Items were presented on sheets of paper. The items consisted of self- and emotion-focused sentences such as "think about the way you feel" and "think about the level of motivation you feel right now."

Assessment of dysphoric mood. Ratings of mood were obtained with a VAS that was administered before and after the mood manipulation, and following the rumination induction. Each VAS consisted of a 152 mm line with arrows indicating increased strength of happy and sad moods from the middle of the scale (scale labeled "sad" and "happy" at each extreme). Responses were scored on a scale ranging from 0 to 152 with higher scores indicating greater dysphoric mood.

Negative self-judgments. In line with prior studies (Rimes & Watkins, 2005), measures of negative self-judgments were obtained to assess the impact of rumination on participants' cognition. Ratings of "worthless," "unlovable," "acceptable," and "competent" (final two reverse scored) were obtained with four VAS before and after the mood manipulation and immediately following the rumination induction. Each scale consisted of a 152 mm line (labeled "Not at all" to "Totally" at each extreme) and were scored on a scale ranging from 0 to 152, where increased scores indicated greater negative self-judgments. To ease interpretation and comparison with prior research, ratings of worthlessness and incompetency were combined to form a total score of autonomy-type judgments (i.e., achievement-based evaluations), whereas ratings of unacceptability and unlovability were combined to form a total score of sociotropy-type judgments (i.e., interpersonal evaluations; Rimes & Watkins, 2005).

Experimental task of habit versus goal-directed behavior control. The Fabulous Fruit Game (FFG; see Figure 1) is a computerized outcome devaluation task (programmed in Visual Basic 6.0) designed to measure the extent to which instrumental performance is under the control of habitual versus goal-directed action strategies. We used a modified version (see Worbe et al., 2015) of the original FFG (De Wit et al., 2007; Gillan et al., 2011). This experimental task infers an increased reliance on habit over goal-directed behavior control when a previously rewarded and overlearned response to a cue (instrumental training) persists even though the reward is devalued (i.e., slips-of-action; for a detailed summary, see Worbe et al., 2015).

Instrumental training. Participants were presented with a series of six boxes with pictures of fruits on them (see Figure 1), presented one at a time at the center of the screen. Each box had a unique fruit image on the front (e.g., bananas) and a different fruit image inside (e.g., pineapple). Participants learned two instrumental responses (left or right button-presses) to gain rewarding outcomes (earn points by collecting fruits inside boxes). The fruits inside the boxes were worth points (cumulative scores shown on the screen). Correct responses revealed the fruit outcome inside (points awarded) but incorrect responses showed an empty box (no points awarded). The fruits on the outside served as discriminative stimuli (three fruits signaled that the right response was correct, and the other three that the left response was correct). Participants were instructed to learn by trial and error which was the correct response (left versus right) for each outcome (fruit inside) and to try to earn

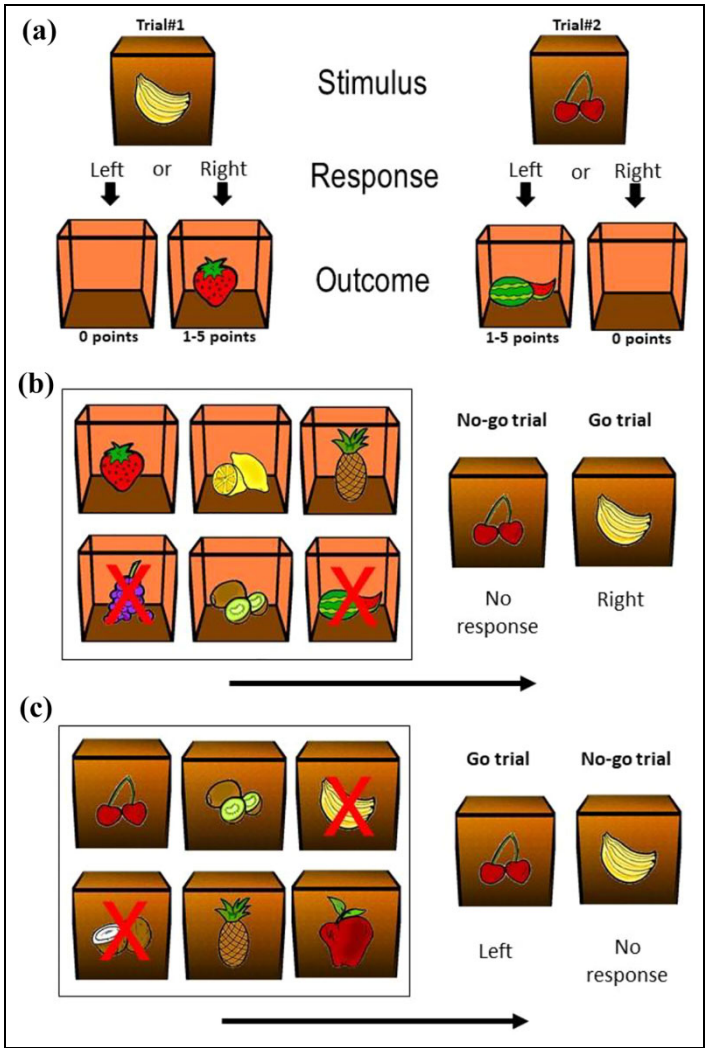

Figure 1. The Fabulous Fruit Game. (a) Instrumental learning phase. Two example trials are shown. On each trial, participants were presented with a closed box with a fruit image on the front (i.e., banana or cherry). Participants could open each box with either left or right button-press. If the correct response was selected (e.g., the right button-press for the banana box), another fruit reward was shown inside the box. If the incorrect response was selected, an empty box was shown. Participants could earn 1–5 points for each correct response (depending on how fast the response was made) and 0 points for an incorrect response. (b) The slips-of-action test. In this example, participants were presented with a display of six boxes with fruits inside. Two of the fruits were marked with a red cross which meant they were devalued and that participants would lose points if they opened boxes that included these fruits. Following the display, each box was presented in rapid succession (2 s per trial). Participants were instructed to withhold responses to boxes with devalued fruits ("no-go" trials) but respond to other boxes ("go" trials). In this example, the box with cherry on the front represents a "no-go" trial (as it contains the devalued melon inside) and the box with banana on the front represents a "go" trial (as it contains the still-valuable strawberry inside). (c) The baseline control test. In this example, the display shows six closed boxes with fruit stimuli on the front. Again, two boxes are marked with red crosses which means they are devalued. Following the display, each box was presented in rapid (2 s) succession. Participants were instructed to withhold responses to boxes with devalued fruits on front ("no-go" trial) but respond to other boxes ("go" trials).

as many points as possible, with more points awarded for faster correct responses (from 1 to 5 points).

Slips-of-action test. This test was designed to assess the relative contribution of habitual versus goal-directed control over instrumental responses learned during the instrumental training phase. Each of the nine test blocks consisted of a 10-s screen that presented all the six different fruit outcomes (i.e., the six fruit outcomes inside the boxes) from the initial learning phase. Two of the six fruits had a red cross on them, indicating that they were now devalued and collecting them would result in subtraction of points. Following the 10-s presentation, each of the boxes was presented one at a time in quick succession, showing only the discriminative stimulus (the fruit image outside the box). Participants earned points by pressing the correct response to collect the still-valuable fruit outcomes inside. However, they were instructed to refrain from responding to the boxes that contained the devalued fruit inside, since it led to subtraction of points (see Figure 1). No feedback of correct or incorrect responses was provided during this stage (i.e., the boxes remained closed). Failure to withhold responses to stimuli linked with devalued outcomes (i.e., "slips-of-actions") is thought to reflect an increased reliance on stimulus–response habits. In contrast, selective responses to valuable as opposed to devalued outcomes, on the basis of current outcome value, are thought to reflect goal-directed action control. Participants completed 108 trials over nine blocks with each of the six discriminative stimuli presented two times per block in random order. Each outcome was devalued three times across all blocks. Although similar to traditional cognitive inhibition tasks (e.g., go/no-go tasks), that tap the ability to override prepotent responses and inhibiting the processing of irrelevant material (i.e., inhibiting stimulus–response associations), outcome devaluation was designed to measure the ability to alter an overtrained response based on changes in outcome contingencies (i.e., altering response–outcome associations). However, it is possible that outcome devaluation involves some form of higher order cognitive control processes. The outcome devaluation task therefore includes a control test (see baseline test below) to account for general test demands on working memory and response inhibition (De Wit, 2017).

Baseline test. This additional test was randomly performed either before or after the slips-of-action test (see Figure 1). The baseline test was designed to control for general test demands on working memory and response inhibition of the slips-of-action test. It had an identical structure to the slips-of-action test, the only difference being that the discriminative stimuli (fruits outside the box) were devalued rather than the outcomes (fruits inside the box). Therefore, this test did not require an evaluation of the anticipated outcome of one's action as the slips-of-action test and was intended to account for individual differences in general executive control on the task, independent of sensitivity to outcome devaluation.

Procedure

The study was approved by the National Bioethics Committee and reported to the Icelandic Data Protection Authority. The measures were administered over a single session in a quiet and well-lit room. Participants first answered self-report questionnaires (BDI-II, RRS, HINT, and COHS) and partook in the rumination induction task (administered in a counterbalanced order). Finally, they participated in the FFG experimental task. This study is part of a larger multi-study research project that also included measures of emotion regulation, depression vulnerability, and experience sampling of mood and cognition.

Statistical analyses

A priori power analyses using G*power (Faul et al., 2007) indicated that a sample of 110 participants would yield .9 power to detect small regression effect sizes ($f = .15$) with four predictor variables and medium bivariate correlations ($p = .3$). We therefore aimed for recruiting a sample of 110–120 participants. The IBM SPSS 24 Statistics package was used to calculate Pearson's correlation, hierarchical linear regressions, and mixed ANCOVA with Greenhouse–Geisser correction if assumption of sphericity was violated. To assess multicollinearity in the regression analyses, we looked at the variance inflation factor (VIF) which did not indicate problems due to multicollinearity in any of the analyses (VIF values ranged between 1.000 and 1.720). All statistical tests were two-sided (α level $= .05$) with confidence intervals (CIs) of 95%. Effect sizes were estimated using Cohen's d, partial eta-squared (partial η^2), and change in R^2. For discriminative performance on the FFG, a Devaluation Sensitivity Index (DSI; see also Snorrason et al., 2016) was computed for the slips-of-action test and baseline test. The DSI was constructed by subtracting the percentage of responses to cues linked

Table 1. Descriptive statistics of self-report questionnaires and the rumination induction and habit control tasks used in the study ($N = 115$).

	Mean (*SD*)	Range	Cronbach's α
Self-report questionnaires			
BDI-II	15.25 (10.16)	0–43	.91
RRS	49.21 (11.79)	24–82	.90
Brooding	11.21 (3.43)	5–20	.80
Reflection	10.08 (3.42)	5–18	.76
HINT	51.33 (16.72)	12–84	.93
COHS automaticity	33.53 (7.71)	17–51	.78
COHS routine	55.72 (10.27)	24–79	.85
Rumination induction task			
Mood			
T1: Baseline	57.64 (26.99)	1–138	
T2: Post-mood manipulation	83.47 (32.50)	1–147	
T3: Post-rumination induction	69.43 (29.47)	0–152	
Worthlessness/incompetency			
T1: Baseline	74.39 (55.07)	0–207	
T2: Post-mood manipulation	83.13 (60.32)	0–204	
T3: Post-rumination induction	76.13 (65.09)	0–242	
Unlovability/unacceptability			
T1: Baseline	66.19 (52.23)	0–190	
T2: Post-mood manipulation	77.00 (60.79)	0–251	
T3: Post-rumination induction	74.92 (62.26)	0–245	
Habit control task			
Slips-of-action test			
Valued outcome	89.83 (9.93)	60–100	
Devalued outcome	28.08 (25.12)	0–97	
Baseline test			
Valued outcome	96.15 (4.65)	76–100	
Devalued outcome	14.09 (13.41)	0–100	

Note. HINT = Habit Index of Negative Thinking; COHS automaticity = Creature of Habit Scale–automaticity subscale; COHS routine = Creature of Habit Scale–routine subscale; brooding = Rumination Responses Scale–brooding subscale; reflection = Rumination Responses Scale–ruminative reflection subscale; RRS = Rumination Responses Scale–total score; BDI-II: Becks Depression Inventory-II; T1 = Time 1; T2 = Time 2; T3 = Time 3.

to devalued outcome from the percentage of responses to cues linked to valued outcomes. Thus, lower DSI values on the slips-of-action test reflected less sensitivity to devaluation (i.e., habitual responding).

Results

Rumination and habitual characteristics

Descriptive statistics for self-report measures and experimental tasks are presented in Table 1. To determine whether the heightened disposition to engage in ruminative brooding was associated with greater habitual characteristics, we first computed bivariate zero-order correlations between trait rumination (RRS) and self-report measures of habits (see Table 2). As expected, HINT was positively correlated with ruminative brooding but not ruminative reflection, indicating that only brooding shares habitual characteristics with negative thinking. The same pattern was observed in the relationship between rumination and the automaticity and routine scores of the COHS, where brooding, but not reflection, was significantly and positively correlated with scores on both facets. Thus, heightened ruminative brooding, but not reflection, was associated with greater habitual characteristics of negative thinking and general propensity to habitual responding.

Rumination induction and habitual characteristics

Two participants did not follow the instructions for the rumination task, since both had multiple ratings of mood and negative self-judgments on each

measurement occasion. Their data were therefore removed, leaving data from 113 subjects to be analyzed for the rumination task.

Mood manipulation. A paired samples *t*-test confirmed an expected increase in dysphoric mood from baseline (Time 1) to post-mood manipulation (Time 2), $t(114) = -9.768$, $p < .001$, CI $= -30.22, -20.82$, $d = 1.027$ (Table 1). There was also a significant increase from Time 1 to Time 2 in negative self-judgments of worthlessness/incompetency, $t(114) = -2.609$, $p = .010$, CI $= -15.38, -2.10$, $d = .243$, and unacceptability/unlovability, $t(114) = -3.613$, $p < .001$, CI $= -25.99, -6.96$, $d = .165$. The mood manipulation therefore had a detrimental effect on both mood and the evaluation of self-worth (Table 1).

Table 2. Bivariate correlations between RRS, HINT, and COHS scores ($N = 115$).

	RRS brooding	RRS reflection
	r(113)	*r*(113)
HINT	.428**	.157
COHS automaticity	.294*	.174
COHS routine	.311**	.069

Note. HINT = Habit Index of Negative Thinking; COHS automaticity = Creature of Habit Scale–automaticity subscale; COHS routine = Creature of Habit Scale–routine subscale; RRS brooding = Rumination Responses Scale–brooding subscale; RRS reflection = Rumination Responses Scale–ruminative reflection subscale.
*$p < .01$. **$p < .001$.

Rumination induction. To test the hypothesis that greater habitual characteristics (HINT) and habit propensity (COHS) would be associated with greater persistence of dysphoric mood during rumination induction, we performed a three-step hierarchical regression using post-rumination induction (Time 3) mood scores as the dependent variable. The results are summarized in Table 3. Mood scores at Time 2 were entered at Step 1 to control for mood at the start of the rumination induction.[1] Given the high correlation between self-report measures of ruminative brooding and habit in the current study, ruminative brooding (RRS) was entered at Step 2 as a more conservative test of the relation between the effects of rumination induction and habitual responding. Ruminative brooding (RRS) entered at Step 2, significantly added

Table 3. Result from hierarchical regression analyses (final step) using ruminative brooding, habitual characteristics of negative self-thinking, and general habitual response tendencies to predict mood and negative self-judgment scores in the rumination induction task ($N = 113$).

	B	*SE B*	β	95% CI
DV: Mood, T3				
Step 1 ($\Delta R^2 = .658$***)				
Mood, T2	.654	.052	.721***	.550, .757
Step 2 ($\Delta R^2 = .029$**)				
Brooding	1.177	.505	.137*	.176, 2.178
Step 3 ($\Delta R^2 = .012$*)				
HINT	.224	.108	.126*	.011, .438
DV: Worthlessness/incompetency, T3				
Step 1 ($\Delta R^2 = .766$***)				
Worthlessness/incompetency, T2	.910	.065	.842***	.780, 1.039
Step 2 ($\Delta R^2 = .009$*)				
Brooding	2.123	.974	.112*	.193, 4.053
Step 3($\Delta R^2 = .000$)				
HINT	−.091	.235	−.023	−.557, .375
DV: Unlovability/unacceptability, T3				
Step 1 ($\Delta R^2 = .777$***)				
Unlovability/unacceptability, T2	.847	.055	.827***	.738, .955
Step 2 ($\Delta R^2 = .004$)				
Brooding	1.005	.912	.055	−.804, 2.813
Step 3 ($\Delta R^2 = .003$)				
HINT	.239	.203	.064	−.164, .642

Note. HINT = Habit Index of Negative Thinking; brooding = Rumination Responses Scale–brooding subscale; T2 = Time 2; T3 = Time 3.
*$p < .05$. **$p < .01$. ***$p < .001$.

to the model and was associated with greater persistence of dysphoric mood. Finally, HINT, entered at Step 3, was a significant predictor of greater persistence of dysphoric mood over and above all previously entered variables. Neither COHS routine nor automaticity scores significantly contributed to the prediction of mood when entered simultaneously at Step 3 instead of HINT (all ps > .37). In summary, after controlling for ruminative brooding, habitual characteristics of negative thinking (HINT), but not general automatic and routine response tendencies (COHS), significantly predicted greater persistence of dysphoric mood following rumination induction.

We next determined whether greater habitual characteristics were associated with a greater persistence of negative self-judgments during rumination induction. We repeated the three-step regression analysis with Time 3 negative self-judgments as the dependent variable (see Table 3). The results showed, that for worthlessness/incompetency as the outcome, ruminative brooding (Step 2), but not HINT (Step 3), emerged as a significant predictor after controlling for Time 2 worthlessness/incompetency scores. Neither ruminative brooding nor HINT added significantly to the prediction of negative self-judgments when unacceptability/unlovability was the outcome. When performing the same analyses using COHS routine and automaticity scores, neither significantly added to the prediction of worthlessness/incompetency nor unacceptability/unlovability (all ps > .44). Thus, only ruminative brooding showed a significant association with the detrimental effects of rumination induction on the evaluation of self-worth.

Habitual characteristics and the immediate response to dysphoric mood

To assess the specificity of these findings, we also explored whether habitual characteristics (HINT) and habit propensity (COHS) were related to the immediate effects of the mood manipulation more generally. In the rumination task, Time 2 mood and negative self-judgment scores were regressed on the habit indices using six three-step hierarchical regressions. When controlling for Time 1 mood and negative self-judgment scores (Step 1), ruminative brooding, entered at Step 2, did not add to the prediction of Time 2 mood and negative self-judgments (all ps > .216). HINT, entered at Step 3, emerged as a significant predictor of Time 2 mood ($\beta = .478$, $p = .002$, $\Delta R^2 = .050$, $p = .002$, 95% CI = .175, .781), worthlessness/incompetency ($\beta = .243$, $p < .001$, $\Delta R^2 = .038$, $p < .001$, 95% CI = .404, 1.365), and unacceptability/unlovability ($\beta = .127$, $p = .034$, $\Delta R^2 = .011$, $p = .034$, CI = .035, .898). However, neither COHS routine nor COHS automaticity, simultaneously entered at Step 3, significantly added to the prediction of Time 2 mood and negative self-judgments (all ps > .10). Therefore, greater habitual characteristics of negative thinking, but not more general habitual response tendencies nor ruminative brooding, were associated with greater immediate shifts in dysphoric mood and negative self-judgments in response to the mood manipulation.

Ruminative disposition and habit-directed behavior control

Finally, it was investigated whether a heightened ruminative disposition was associated with a greater habit relative to goal-directed behavior control using the FFG outcome devaluation task. There was a significant main effect of block in the FFG instrumental learning stage (mixed ANCOVA), $F(4.243, 462.453) = 11.436$, $p < .001$, partial $\eta^2 = .265$, but no significant interaction between the effect of block and the rumination indices or BDI-II. This confirms that discriminative performance improved during the learning phase of the task and at a rate independent of the degree of ruminative disposition or depression. As expected, participants responded significantly more often to stimuli associated with valued outcome than stimuli related to devalued outcome, on both the slips-of-action test (89.8% vs. 28.1%), paired samples t-test, $t(114) = 21.013$, $p < .001$, CI = 55.9, 67.6, $d = 1.959$, and the baseline test (96.2% vs. 14.1%), paired samples t-test, $t(114) = 52.720$, $p < .001$, CI = 79.0, 85.1, $d = 4.919$.

Hierarchical linear regression, with slips-of-action DSI as the outcome, showed that when baseline DSI ($\beta = .424$, $p < .001$, $\Delta R^2 = .177$, $p < .001$, CI = .478, 1.122) was entered at Step 1, to control for general test performance variables, followed by ruminative brooding ($\beta = -.016$, $p = .871$, $\Delta R^2 = .001$, CI = −.762, 1.410) at Step 2, and rumination induction change scores in mood ($\beta = -.172$, $p = .059$, CI = −.568, .08) at Step 3, the baseline DSI was the only significant predictor of reliance on habit relative to goal-directed learning (slips-of-action DSI). The same pattern was found when entering rumination induction change scores in worthlessness/incompetency and unacceptability/unlovability at Step 3 (all

*p*s > .14). Thus, a heightened ruminative disposition was not characterized by greater habit relative to goal-directed behavior control. Analyzing first-order partial correlations, while controlling for the baseline DSI, showed that slips-of-action DSI was not related to HINT, $r(113) = -.002$, $p = .979$, nor COHS routine, $r(113) = -.133$, $p = .159$, or automaticity, $r(113) = .084$, $p = .375$.

Discussion

The purpose of the present study was to investigate whether rumination can be construed as a form of habitual thinking, a widely held notion that has rarely been directly tested. It is noteworthy that no previous study has investigated this using a combination of both self-report and experimental measures of rumination, adding to the relatively small number of studies in this area (Ólafsson et al., 2020; Van Vugt et al., 2018; Verplanken et al., 2007; Watkins & Baracaia, 2001).

The hypothesis that habitual characteristics of negative thinking would be associated with the tendency to engage in ruminative brooding, but not ruminative reflection, was supported. Heightened self-reported ruminative brooding, but not ruminative reflection, was associated with greater habitual characteristics of negative thinking measured with the HINT (i.e., repetition, automaticity, lack of conscious awareness and intent, mental efficiency, lack of control, and self-descriptiveness). This novel finding is in line with Hertel's (2004) conceptualization of depressive rumination as an automatic and involuntary habitual process and with previous research (Ólafsson et al., 2020; Verplanken et al., 2007). It also provides support for the habit-goal framework of rumination (Watkins & Nolen-Hoeksema, 2014), which states that when rumination is in the form of an analytical and abstract processing style (i.e., brooding), it is more likely to develop into a mental habit when compared to a more concrete and solution-focused way of thinking (i.e., ruminative reflection). Although there is conflicting evidence regarding the relative contribution of ruminative brooding and ruminative reflection to depression vulnerability (Joormann & Gotlib, 2010), the current findings hint at differential effects between the two forms of rumination, with only brooding showing an association with habitual negative thinking. These findings are in line with the suggestion that depression vulnerability may be in the form of ruminative brooding, but not reflection, being habitually triggered (without awareness or intent), making it difficult to control (Watkins & Nolen-Hoeksema, 2014).

Of critical importance, the association between ruminative brooding and habitual characteristics of negative thinking was also evident when rumination was experimentally induced. Rumination that has become habitual should be associated with more adverse consequences (Hertel, 2004; Watkins & Nolen-Hoeksema, 2014). It was therefore expected that habitual characteristics of negative thinking would predict increased persistence of negative affect and cognition in the rumination task. This was partially supported. Habitual characteristics of negative thinking predicted a greater persistence of dysphoric mood, indicating that rumination may be more detrimental when it is associated with habitual attributes. It is important to note that habitual characteristics of negative thinking added to the prediction of persistence of dysphoric mood on the rumination task, over and above what could be accounted for by the RRS alone—a well-established measure of depressive brooding. This underlines the possible additive value of considering habit-like automaticity of thoughts in the study of adverse consequences of ruminative thinking.

Contrary to predictions, habitual characteristics of negative thinking were not associated with a greater persistence of negative self-judgments following the rumination induction. Since participants are instructed to ruminate in the rumination induction task (Nolen-Hoeksema & Morrow, 1993), it is possible that the task may not be optimally suited to capture the effects of habits because the instructions may draw attention to the habitual behavior under question, reducing its effect (e.g., Spieler & Miltenberger, 2017). Future research should endeavor to elucidate this using experimental tasks that might better capture naturally occurring ruminative thoughts in response to negative mood, such as providing a subsequent no-task delay period that allows the opportunity for spontaneous rumination (e.g., Conway et al., 2000; Thomsen et al., 2004).

Interestingly, habitual characteristics of negative thinking were also related to the initial increase in negative mood and negative self-judgments following the mood challenge. This suggests that habitual thinking may play a role in increasing mood-related vulnerability more generally. The current findings therefore highlight the need to clarify the unique role of habit in depressive rumination and whether it relates to other vulnerability factors that are also

thought to be contingent on negative mood, such as cognitive reactivity (Lau et al., 2004) and dysfunctional emotion regulation (Joormann & Stanton, 2016).

There is limited research into the specific factors that might contribute to rumination becoming habitual. The habit-goal framework broadly specifies personal and environmental factors that lead to inflexible responding as possible mechanisms (Watkins & Nolen-Hoeksema, 2014). In the current study, we tested whether rumination was associated with greater habit relative to goal-directed behavior control, since difficulties in goal-directed control might contribute to faster and stronger formation of habit (Linnebank et al., 2018) and might thus predispose some to develop rumination as a habit. Ruminative brooding, but not ruminative reflection, was correlated with greater habitual responding in everyday life on the COHS, a self-report measure of habit propensity. However, this was not the case when using an outcome devaluation task of habit formation. Thus, rumination seems to be related to self-reported automatic and routine responding in daily life, but no evidence was found for greater tendency toward general habit-related, at the expense of more goal-directed, behavior control on an experimental task involving outcome devaluation. This novel exploration therefore calls attention to the strong association of rumination with habitual responding in daily life but does not, however, find support for the notion that greater habit relative to goal-directed behavior control contributes to rumination as a habit.

Surprisingly, the two measures of habit propensity (i.e., COHS and FFG) were not significantly correlated, suggesting that they might tap different aspects of the habit construct. However, this discrepancy might also be attributed to differences in method variance and the use of a student a sample. Furthermore, it is possible that greater habit propensity only becomes evident when negative mood interferes with goal-directed control. Indeed, depression is strongly associated with negative life events and chronic forms of stress (Hammen, 2005; Nelson et al., 2017) that might impair the ability to use effortful and goal-directed behavioral control (Beevers, 2005; Snyder, 2013). It is possible that self-report measures of everyday habit propensity better capture the individuals' responses to everyday stressful and negative events, whereas the outcome devaluation task used in the present study includes only neutral stimuli. In future studies, it might be interesting to explore the application of outcome devaluation tasks with emotional or disorder-specific stimuli.

Collectively, the findings from the current study provide initial support for the notion of rumination as a habit as defined by the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) and developmental frameworks of rumination (Shaw et al., 2019). The results are in line with the suggestion that depression vulnerability may be in the form of ruminative brooding being habitually triggered (without awareness or intent), making it difficult to control. Moreover, they underscore the predictive value of considering habit when explaining the effect that rumination has on depressive mood. However, rumination was not consistently associated with a greater habit propensity, setting boundary conditions in the search for specific factors that might contribute to rumination becoming habitual. Although the results should be considered preliminary and interpreted in light of the correlational nature of the study, they represent one of the first attempts to test hypotheses directly derived from the novel habit-goal framework. It is well established that heightened ruminative brooding in response to negative mood is associated with increased depression vulnerability, although, the cognitive factors that contribute to a ruminative disposition are only now starting to become clear. A unique contribution of the current study is the assessment of individual differences in ruminative brooding using not only a self-report measure but also an experimental rumination induction approach. By showing that the heightened tendency to engage in ruminative brooding may be associated with greater habitual characteristics of negative thinking, the present study has identified habitual thinking as a possible contributor to depressive rumination.

Despite the contributions of the current study, some limitations and directions for future research are noteworthy. The majority of the sample were female students, which might preclude the generalization of the findings to males and clinical groups differing in disorder severity. Because the present study involves a correlational design, we cannot provide a definite test of rumination as a true habitual response. The causal nature of the relationship between ruminative brooding and habitual characteristics of negative thinking therefore remains uncertain. To the best of our knowledge, no such direct test of rumination as a habit exists. To address this limitation in future research, it would be of value to determine whether interventions that are presumed to target the habitual

nature of ruminative thinking (cf. Watkins, 2018) can reduce the habitual characteristics of negative thinking and thus alter the disposition to engage in ruminative brooding. Such a finding would indicate that habitual characteristics play a significant role in explaining individual differences in the disposition to engage in ruminative brooding. Future research could also address this limitation by testing context–response associations in line with the habit-goal framework using experience sampling methodology (Myin-Germeys et al., 2018). It could be tested whether habitual characteristics of negative thinking predict greater levels of momentary rumination in response to daily fluctuations in negative affect, providing conformation that habitual characteristics play an important role in ruminative brooding as it occurs in situ. The findings of the current study therefore provide clinically relevant and testable hypothesis that might lead to a greater understanding of interventions that successfully target ruminative brooding, thereby enhancing the treatment and prevention of depression

To conclude, findings from the current study provide initial support for the habit-goal framework of depressive rumination (Watkins & Nolen-Hoeksema, 2014) and underscores the predictive value of considering habit when explaining the effect that ruminative brooding has on depressive mood. Future studies should aim to test the predictions of the habit-goal framework using experimental and experience sampling methodology, to obtain information on the habitual contingency between negative mood and depressive rumination and the specific factors that might contribute to habitual rumination.

Authors' Note

Ivar Snorrason is also affiliated with Massachusetts General Hospital, USA.

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Note

1. Another option would have been to control for mood scores at Time 1. However, this might confound changes during the rumination induction with the initial shift in mood and cognition attributable to the mood induction, which has been found to be related to other vulnerability factors in depression (e.g., cognitive reactivity, mood reactivity, and emotion regulation strategies). We therefore chose to control for T2 as a more conservative test of the relation between habit and rumination induction.

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Paper II

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Do daily mood fluctuations activate ruminative thoughts as a mental habit? Results from an ecological momentary assessment study☆

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ABSTRACT

It has been suggested that mental habits may underpin a heightened disposition to engage in rumination in response to negative mood. The aim of the current study was to assess the role of habit in the dynamic interplay between affect and ruminative thinking in the flow of daily life experiences. Using mobile ecological momentary assessment, 97 participants recorded affect and rumination ten times daily over six days, after completing measures of trait ruminative brooding and habitual characteristics of negative thinking (e.g. automaticity, lack of conscious awareness, intent and control). Momentary fluctuations in negative (increased) and positive (decreased) affect was prospectively associated with greater rumination-levels at the next sampling occasion. The degree to which affect triggered a subsequent ruminative response was moderated by habitual characteristics of negative thinking in a theoretically consistent way. Stronger temporal pairing of negative affect and rumination was also associated with greater emotional inertia but less carry-over of rumination from one moment to the next. Depression vulnerability may be in the form of rumination being habitually triggered in response to momentary fluctuations in affect, with deleterious effect on mood. The findings may have clinical implications, as targeting the habitual nature of rumination might help reduce depression vulnerability.

1. Introduction

Ruminative thinking is critical in the onset and maintenance of major depressive disorder (Wisco & Nolen-Hoeksema, 2008) and has been identified as a transdiagnostic vulnerability factor for a number of aversive outcomes (e.g. anxiety, eating disorder, alcohol misuse; Aldao, Nolen-Hoeksema, & Scweizer, 2010). Rumination is a negative thinking style that involves repetitively and passively dwelling on the causes, meanings, and consequences of one's feelings and distress (Nolen--Hoeksema, 1991). Considerable evidence suggests that rumination exacerbates negative affect and cognition, impairs problem solving, and leads to more persistent periods of dysphoric mood (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008).

The Response Styles Theory defines rumination as an enduring, stable, and *habitual-like tendency* (Nolen-Hoeksema et al., 2008) suggesting that mental habits may underpin a heightened disposition to engage in rumination. This is in line with descriptions of rumination as a habit in the depression literature (see e.g. Hertel, 2004; Watkins & Baracaia, 2001) and recent theoretical conceptualizations of depression vulnerability (e.g. Farb, Irving, Aderson, & Segal, 2015; Koster, De Lissnyder, Derakshan, & De Raedt, 2011; Shaw, Hilt, & Starr, 2019). Habits are formed by learned associations between behavioural responses and their performance contexts. Once formed, context cues become automatic triggers for the behaviour, such that it is controlled solely by the presence of the context cue, rather than individual's goals or motivations (Triandis, 1977; Wood & Neal, 2007). Habits are characterized by a lack of awareness and conscious intent, are mentally efficient, and can be difficult to control (Verplanken, Friborg, Want, Trafimow, & Wolf, 2007).

Watkins and Nolen-Hoeksema (2014) proposed a habit-goal

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framework wherein rumination is seen as a mental habit that is initiated without conscious awareness or intent in response to negative mood. Transient periods of rumination are thought to arise when people try to cope with discrepancies between desired states and their present reality. This process is considered adaptive when ruminating about the discrepancy helps reach important goals, however, when goals are repeatedly not reached, rumination persists and mood deteriorates (Martin & Tesser, 1996; Watkins, 2008). When people consistently rely on passive, negative and abstract ruminative thoughts to cope with such discrepancies, negative affect and ruminative thinking are paired over time, turning rumination into a habit that is triggered by context (i.e., negative affect) rather than goals or intentions. Maladaptive rumination is therefore expected to be associated with heightened habitual characteristics (i.e., be more repetitive and automatic) compared to other less maladaptive forms of rumination.

Nonetheless, the notion of rumination as a mental habit has rarely been directly tested. Verplanken et al. (2007) used the Habit Index of Negative Thinking (HINT) - a self-report measure of habitual characteristics of negative thoughts (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness) - and found that ruminative thoughts were strongly correlated with heightened habitual characteristics. Consistent with this, Ólafsson, Guðmundsdóttir, Björnsdóttir, and Snorrason (2020) found that ruminative brooding, a maladaptive form of rumination, was associated with heightened habitual characteristics whereas ruminative pondering, a more adaptive form of rumination, was not. Although promising, these findings are limited in a number of ways. Because rumination is measured at a single time point and averaged across time, they may not generalize to momentary fluctuations in rumination and affect. Participants also report on their rumination by thinking back to a time when they felt sad and recall their experiences, increasing the probability of retrospective bias. In a similar vein, previous findings do not allow for an inference about the temporal relationship between affect and rumination, rendering causal inference impossible.

One way to address these shortcomings is to use more ecologically valid assessment procedures, such as Ecological Momentary Assessment (EMA), to capture fluctuations in thinking and affect in the flow of daily life experiences (e.g. Myin-Germeys, 2018; Shiffman, Stone, & Hufford, 2008). Studies using EMA have revealed a reciprocal relationship between rumination and affect, with rumination predicting negative affect at a subsequent measurement occasion, and negative affect predicting subsequent rumination to the same effect (Moberly & Watkins, 2008). They also show that a strong temporal relationship between negative affect and subsequent rumination is associated with heightened symptoms of depression and greater emotional inertia (Brose, Schmiedek, Koval, & Kuppens, 2015), that is the increased carry over of negative emotions from one moment to the next (Kuppens, Allen, & Sheeber, 2010).

We are not aware of any EMA studies that directly test the assumption that fluctuations in negative affect trigger rumination across time as a function of habit. Furthermore, the relationship of such habitual rumination with emotional inertia remains unclear. Given that habits might explain persistent patterns of rumination (Shaw et al., 2019), which in turn have been associated with greater emotional inertia (Koval, Kuppens, Allen, & Sheeber, 2012), it may be that habitually ruminating in response to negative affect contributes to more persistent negative mood states (i.e., greater inertia). Consistent with this, Brose et al. (2015) found that a strong temporal pairing of affect-rumination tended to co-occur with emotional inertia, such that individuals with heightened symptoms of depression tended to be characterized by both high levels of emotional inertia and a strong temporal pairing of affect-rumination. Finally, to our knowledge no study has assessed how habitual rumination relates to everyday levels of positive affect, which may be an important resilience factor that reduces momentary rumination (Hoorelbeke, Van den Bergh, Wichers, & Koster, 2019). Although failed resolution of goals has usually been associated with increases in negative affect, it is equally possible that it results in detrimental changes in the momentary experiences of positive affect, and that decreased levels of positive affect and ruminative thinking may be paired over time. In line with this, depression has not only been associated with greater levels of momentary negative affect but also decreased levels of everyday positive affect (Telford, McCarthy-Hones, Corcoran, & Rowse, 2012). However, the relevance of positive affect to the rumination process is relatively understudied and therefore not well understood, and the possible link between changes in positive affect and subsequent rumination therefore exploratory in nature.

1.1. The present study

The aim of the current study was to assess if the habitual characteristics of negative thoughts are related to the dynamic interplay between negative affect and ruminative thinking in the flow of daily life experiences. In line with vulnerability-stress models of depression (Abramson et al., 2002; Ingram & Luxton, 2005) and recent emphases on dimensional approaches to the study of mechanisms contributing to psychopathology (Kozak & Cuthbert, 2016), the study was conducted in a non-selected sample with a wide range of depressive symptoms. We utilized EMA wherein participants provide everyday 'in the moment' data about their immediate experiences when prompted by an alarm signal. Momentary affect and rumination were assessed multiple times during the day over a 6-day period, allowing for the assessment of their temporal relationships. As mentioned earlier, advantages of EMA are that it provides findings with high ecological validity (Shiffman et al., 2008) and virtually eliminates retrospective bias (Trull & Ebner-Priemer, 2013). Furthermore, imperative to the measurement of habits, EMA can evaluate fluctuations in affect and rumination over short temporal intervals, allowing researchers to investigate contingencies of which people may be unaware (Neal & Wood, 2009).

We tested two hypotheses derived from the habit-goal framework of depressive rumination (Watkins & Nolen-Hoeksema, 2014) and prior findings (Brose et al., 2015; Hoorelbeke et al., 2019; Moberly & Watkins, 2008). First, we expected increased negative affect to prospectively predict greater rumination-levels at the next sampling occasion. Secondly, because the habit-goal framework predicts that rumination can develop into a mood-linked habit, measures of habit should be specifically associated with the degree to which affect triggers rumination across time rather than just being associated with average levels of momentary rumination. We therefore expected the interplay between negative affect and rumination to be moderated by habit, with increased habitual characteristics of negative thinking predicting greater rumination in response to fluctuations in negative affect. To our knowledge this is the first direct empirical test of the relationship between the habitual characteristics of thought and the dynamic interplay between affect and rumination. We also explored if the same pattern of findings would be apparent when looking at the deterioration of positive affect as a possible trigger for momentary rumination. Finally, given that the temporal pairing of negative affect and rumination has been associated with emotional inertia (Brose et al., 2015) we also explored if habitual characteristic are associated with heightened emotional inertia during the EMA assessment.

2. Method

2.1. Participants

One hundred and fifteen students of various disciplines at the University of Iceland were recruited via an introductory e-mail sent out to all registered students. We requested volunteers for a study on depression vulnerability although we made it clear that participants did not have to be depressed to take part. As intended, we obtained a sample with a wide range of depressive symptoms as measured with the Beck Depression Inventory – II (range = 0–50, M = 14.9, SD = 10.1).

Inclusion criteria were an age between 18 and 65 years and being fluent in Icelandic. Due to technical difficulties seven participants were unable to participate and three dropped out of the study due to time limitations and had no valid responses. Of the participants, 106 completed the EMA measurements. Eight were subsequently excluded due to inadequate EMA compliance (fewer than 10 completed alerts), resulting in a final sample of 97 participants (24 males, 73 females; mean age 23.3 years; SD = 2.81). Participants were rewarded with the equivalent of €30 for their participation.

2.2. Measures

2.2.1. Trait-level questionnaires

2.2.1.1. The ruminative responses scale (RRS; Nolen-Hoeksema & Morrow, 1991). The RRS is a self-report measure of ruminative disposition which contains 22 items that assess a person's tendency to think about the symptoms, causes, and consequences of their depressed mood. The current study utilized the 5-item brooding subscale (RRS-B), which measures more passive, analytical and repetitive forms of thinking, and is thought to represent the maladaptive component of rumination (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). The Icelandic version of the RRS has shown good psychometric properties (Pálsdóttir & Pálsdóttir, 2008). In the current study RRS-B had an $\alpha = 0.91$.

2.2.1.2. Habit Index of Negative Thinking (HINT). The habitual quality of negative thinking was measured with the HINT (Verplanken, Fribort, Wang, Trafimow, & Wolf, 2007), a 12 item self-report scale that measures the degree to which negative thoughts occur frequently, are initiated without awareness, are unintended, are difficult to control, and are self-descriptive. Each item is rated on a 7-point scale in response to the general prompt; "Thinking negatively about myself is something…". and included items such as "I do unintentionally" and "I start doing before I realize I'm doing it". The HINT thus taps the process aspects – the repetitive and automatic nature of the thoughts – which are considered as key elements of mental habits, and which can be distinguished from the content and valence of the thoughts themselves (Verplanken et al., 2007; Watkins, 2008). Evidence of discriminant validity between habitual negative thinking and rumination come from a series of studies by Verplanken et al. (2007) that found HINT to uniquely contribute to feelings of low self-worth over and above rumination, finding them to be related but empirically distinct. Furthermore, a commonality analyses by Gustavson et al. (2019) showed that although HINT shared variance with both rumination and worry in predicting symptoms of depression, HINT also accounted for considerable unique variance not attributable to either rumination or worry. The Icelandic version of the HINT has high internal consistency and good discriminant validity (Ólafsson, Jóhannesdóttir, Jóhannesdóttir, & Hjartarson, 2019). In the current study HINT had an $\alpha = 0.93$.

2.2.1.3. Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996). The BDI-II is a 21 item self-report questionnaire that measures the severity of depression symptoms during the past two weeks. The Icelandic versions of the BDI-II (Arnarson, Ólason, Smári, & Sigurðsson, 2008) has shown good psychometric properties. The BDI-II had an $\alpha = 0.91$ in the current study.

2.2.2. EMA measures

2.2.2.1. Negative and positive affect (NA/PA). Participants rated their current mood at each assessment during the EMA period. The choice of items was based on the widely used Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) and previous EMA studies (revealing items with high loadings on NA and PA latent factors; e.g., Wichers, Lothmann, Simons, Nicolson, & Peeters, 2012). NA consisted of the following items: 1) *I feel sad right now*, 2) *I feel irritable right now*, and 3) *I feel guilty right now*. PA consisted of the items: 1) *I feel happy or cheerful right now*, 2) *I feel enthusiastic right now*, and 3) *I feel satisfied right now*. Participants responded using a five-point Likert scale from 1 (Not at all) to 5 (Very much). NA had an $\alpha = 0.71$ and was strongly correlated with BDI-II ($r = 0.54$; see Table 1) whereas PA had an $\alpha = 0.81$ and was negatively correlated with BDI-II ($r = -0.43$; see Table 1).[1]

2.2.2.2. Momentary Ruminative Self-Focus Inventory - abbreviated (MRSI-A). The MSRI is a 6-item questionnaire that measures state-level fluctuations in ruminative self-focus (Mor, Marchetti, & Koster, 2013). An abbreviated form (Connolly & Alloy, 2017) was chosen for use during the EMA period which contained three items: 1) *Right now, I am thinking about how happy or sad I feel*, 2) *Right now, I wonder why I react the way I do*, and 3) *Right now, I am thinking about the possible meaning of the way I feel*. Participants indicated their degree of rumination at the time of the alert using a 7-point Likert scale, from 1 (Strongly disagree) to 7 (Strongly agree). Both forms of the MRSI have shown excellent internal consistency and are correlated with alternative measures of rumination (Connolly & Alloy, 2017; Mor et al., 2013). In the present study, the MSRI-A had an $\alpha = 0.90$ and was moderately correlated with RRS-B ($r = 0.28$; see Table 1).[1]

2.3. Procedure

During an in-laboratory assessment session, participants completed the trait-level measures (BDI-II, RRS, HINT), were briefed one-on-one on the EMA procedure, and reviewed a sample EMA alert with the researcher to ensure proper understanding of the smartphone app and the sampling procedure. Beginning the following day after the in-lab assessment, participants were prompted by the smartphone app to answer 10 alerts per day for six consecutive days during a 12-h period (between 10 a.m. and 10 p.m.). Alerts were programmed according to a stratified semi-random interval scheme. Each day was divided into ten 72 min intervals, with a signal occurring randomly within each interval, with an average of 92 min between alerts. Each time, participants gave their momentary rating of rumination and affect (PA, NA, MRSI-A). Participants were instructed to answer given how they felt and thought "in the moment" and to complete the measures immediately upon receiving an alert. After receiving an alert, participants had 15 min to respond before it expired. Alerts were presented and responses collected using The Experience Sampler App (Thai & Page-Gould, 2017) an open-source smartphone app intended for ecological momentary assessment research (www.experiencesampler.com). Upon completing the EMA period, participants returned to the laboratory where they were debriefed and received compensation. This study is part of a larger multi-study research project that also included measures of emotion regulation and depression vulnerability that are reported elsewhere (e.g. Hjartarson et al., 2020).

2.4. Statistical analyses

Descriptive statistics were computed using R (R Core Team, 2018). Participants with fewer than 10 out of 60 completed alerts were excluded from the analyses.[2] Given the nested structure of the data (repeated assessments within individuals) we utilized Dynamic Structural Equation Modelling (DSEM) in Mplus 8.1, a multilevel approach to

[1] Correlations are based on within-person averages of NA, PA and MSRI-A.

[2] Previous research has shown that measures with less than 30% completed alerts may be less reliable (Delespaul, 1995). Our results remained virtually unchanged when using a more conservative criteria of at least 20 out of 60 valid alerts. We therefore present results based on a more inclusive sample in our analyses.

analysing EMA data (Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018; Muthén & Muthén, 2017). The models were run using Bayesian estimation with uninformative priors. We used 50.000 Markov Chain Monte Carlo iterations, of which every 10th was recorded for estimation purposes. A Bayesian approach is used in DSEM because it allows for simultaneous estimation of multiple dependent variables and, thus, is suited for examining cross-lagged models and bidirectional effects. Furthermore, it allows for the modelling of time-series data when the interval between measurements are of unequal distance (Schuurman, Ferrer, de Boer-Sonnenschein, & Hamaker, 2016). Another strength of DSEM is that it eliminates biases known to be associated with the use of lagged variables as predictors of autoregressive and other time-varying effects (i.e., Nickell's and Lüdtke's bias; McNeish & Hamaker, 2020).

In order to test our hypotheses, two successive multilevel models were computed, with either NA or PA as a measure of momentary affect. A visual representation of the models is presented in Fig. 1.

In both models, rumination (MRSI-A) and affect (NA/PA) at any given time-point (*t*) were predicted by rumination and affect at the previous time-point (*t-1*). We were interested in the effect of the variables on themselves (autoregressive paths) and on each other (cross-lagged paths). These associations were allowed to differ between individuals (i.e., random means and slopes). We tested whether habitual characteristics (HINT) predicted the strength of the person-specific autoregressive and cross-lagged relationships between rumination and affect. We follow Hamaker (2017), Hamaker, Asparouhov, & Muthén (2017), Hamaker et al. (2018) in presenting our models. The models decompose affect and rumination into latent within- and between-person components. The within-person components describe affect and rumination of individual *i* at time *t*:

$$Affect_{it} = \mu_{Affect,\,i} + \phi_{1i}\, Affect^{(w)}_{it-1} + \phi_{3i}\, Rumination^{(w)}_{it-1} + \zeta_{1it}$$

$$Rumination_{it} = \mu_{Rumination,\,i} + \phi_{2i}\, Rumination^{(w)}_{it-1} + \phi_{4i}\, Affect^{(w)}_{it-1} + \zeta_{2it}$$

where $\mu_{Affect,\,i}$ and $\mu_{Rumination,\,i}$ are the time-invariant (between-person) means of affect and rumination for individual *i*. The autoregressive parameters ϕ_{1i} and ϕ_{2i} represent the effect of the variables at *t-1* on themselves at time *t*. The cross lagged parameters ϕ_{3i} and ϕ_{4i} are the effects of the variables at *t-1* on each other at time *t*. The parameters ζ_{1it} and ζ_{2it} represent the residual variation at time-point *t* not explained by rumination and affect at the previous time-point *t*-1. Both the means μ_i and the lagged parameters ϕ_i are allowed to vary across individuals (hence the subscript *i*). We estimate the effect on HINT on these random effects on the between-level:

$$\mu_{Affect,\,i} = \gamma_{00} + \gamma_{01}\, HINT_i + u_{0i}$$

$$\mu_{Rumination,\,i} = \gamma_{10} + \gamma_{11}\, HINT_i + u_{1i}$$

$$\phi_{1i} = \gamma_{20} + \gamma_{21}\, HINT_i + u_{2i}$$

$$\phi_{2i} = \gamma_{30} + \gamma_{31}\, HINT_i + u_{3i}$$

$$\phi_{3i} = \gamma_{40} + \gamma_{41}\, HINT_i + u_{4i}$$

$$\phi_{4i} = \gamma_{50} + \gamma_{51}\, HINT_i + u_{5i}$$

where $\gamma_{00\text{-}50}$ is the fixed or group average of the parameters and u_i is the individual deviations from these effects. On the between level, HINT, denoted as γHINT, is included as a predictor of the person-specific means and person-specific autoregressive and cross-lagged associations. All the parameters were allowed to covary with each other. We report within-person standardized coefficients. In our models, statistical significance is based on the credible interval not containing zero (the default in DSEM). The corresponding Mplus code is included in the supplementary materials (Supplementary 1).

3. Results

3.1. Preliminary analyses

Participants completed a total of 2710 EMA alerts. Mean number of completed alerts was 33.1 (SD 11.4; range 10–53). See Table 1 for descriptive statistics. HINT was positively correlated with ruminative brooding (RRS), indicating that greater habitual characteristics are associated with a heightened ruminative disposition. On the other hand, HINT, was not correlated with average levels of momentary rumination. As we shall see, this is an example of how time-invariant means are ill-suited at capturing meaningful within-person variation across time.

3.2. Affect and rumination across time

The standardized effects and variances are presented in Table 2 and their corresponding paths are visualized in Fig. 1 [3]. Across both models, the autoregressive values (the effect of the variables on themselves) for NA (ϕNA→NA; B = 0.350) and PA (ϕPA→PA; B = 0.427) were significant, indicating carry-over (inertia) of both affective states from one moment to the next. The autoregressive effect for rumination (MRSI-A) was also significant for both models (ϕRum→Rum; Bs = 0.257 and 0.299) indicating that once initiated, rumination tended to persist.

The cross-lagged values (the effect of the variables on each other over time) revealed paths from affect to rumination, in both models, when controlling for initial levels of rumination (Table 2). The results show that individuals with heightened NA at one moment engaged in more rumination on the next measurement occasion (ϕNA→Rum; B = 0.118), and similarly, that a decline in PA was also predictive of greater rumination at the next measurement (ϕPA→Rum; B = −0.078). Thus, for both negative and positive affect, a within-person deviation from one's own mean level of affect was associated with a subsequent within-person change in rumination.

Surprisingly, no paths were found from rumination to either NA (ϕRum→NA; B = 0.038) nor PA (ϕRum→PA; B = −0.029) meaning that rumination did not predict subsequent changes in affect.[4] The significant variance components in both models (see Ψ values) revealed marked individual variation in all the effects (see Table 2).

The correlations between within-level effects are visualized in Fig. 2. Blue connections represent positive correlations, and red connections represent negative correlations. Individuals with a higher average level of negative affect tended to have more moment-to-moment carry-over in their negative affect. This is evident in the positive correlation (r = 0.187) between the mean μNA and the autoregressive parameter ϕNA→NA. We also observed that when people ruminated to a greater extent in response to heightened negative affect, there was more moment-to-moment carry-over in affect. This appears in the positive correlation (r = 0.109) between the autoregressive parameter ϕNA→NA and the cross-lagged parameter ϕNA→Rum. Also noteworthy, the negative correlation (r = −0.171) between the cross-lagged coefficient ϕNA→Rum and the autoregressive parameter ϕRum→Rum implies that when people ruminate to a greater extent in response to heightened negative affect, there tends to be less carry-over of rumination from one moment to the next. We also note the finding (although weaker) that less carry-over of rumination was associated with greater emotional inertia (ϕNA→NA and ϕRum→Rum; r = −0.044), suggesting that reactive

[3] Unstandardized model parameters are provided in supplementary materials 2.

[4] An analysis of the data revealed that rumination does predict subsequent changes in NA and PA when excluding the between-level predictor HINT. This is consistent with prior findings (e.g., Moberly & Watkins, 2008) showing rumination to predict subsequent changes in affect. However, when accounting for the effects of HINT, and associated parameters, other paths become more predominant.

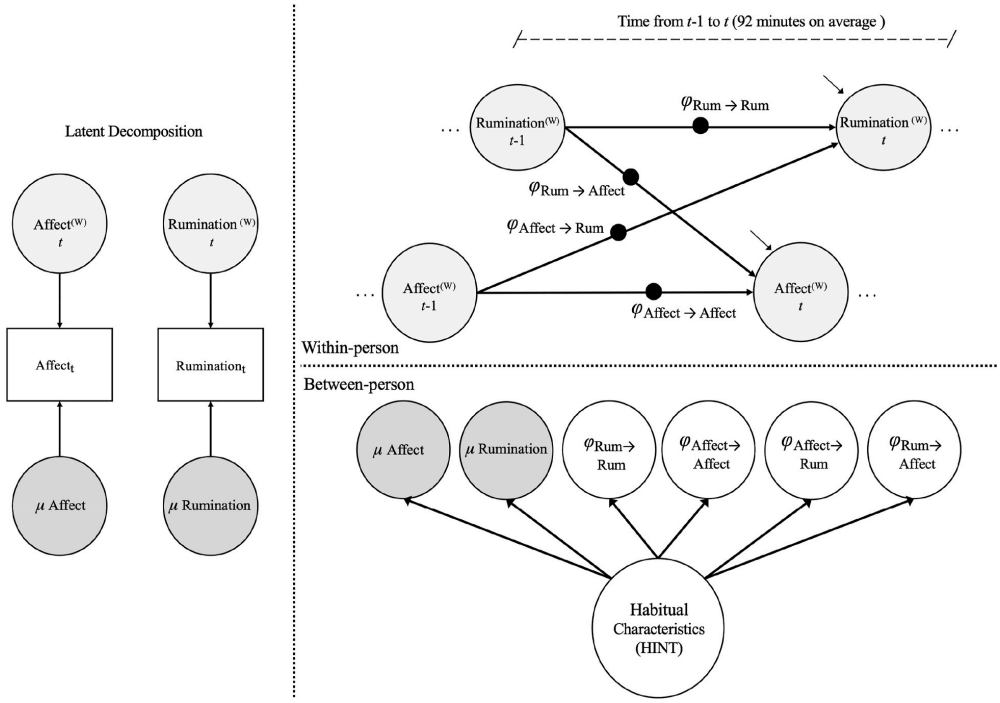

Fig. 1. Multilevel cross-lagged model estimating the effect of habitual characteristics of negative thinking (HINT) on the temporal association between momentary affect (NA/PA) and rumination (MRSI-A). Black dots indicate random effects. (w) represent within-person estimates.

Table 1
Descriptive statistics.

			1	2	3	4	5	6
Trait measures	1	Depressive Symptoms (BDI-II)		0.60***	0.61***	0.54***	−0.42***	0.21*
	2	Ruminative Brooding (RRS-B)			0.51***	0.44***	−0.34***	0.28**
	3	Habitual Characteristics (HINT)				0.55***	−0.32**	0.19
EMA measures	4	Negative Affect (NA)					−0.53***	0.28**
	5	Positive Affect (PA)						−0.03
	6	Momentary Rumination (MRSI-A)						
M			14.88	11.11	51.76	4.33	7.95	6.95
SD			10.08	3.40	16.82	0.80	1.58	3.02
Range			0–50	5–20	12–84	3–15	3–15	3–21

Note. Pearson correlation, $p < 0.001$ '***', $p < 0.01$ '**', $p < 0.05$ '*' (alpha = 0.05).
BDI-II = Beck Depression inventory; RRS = Ruminative Response Scale; HINT = Habit-Index of Negative Thinking; MRSI-A = Momentary Ruminative Self-Focus Inventory.

rather than static levels of ruminative thinking tend to be associated with greater emotional inertia. Also, greater mood-linked rumination was to some extent associated with preceding rumination having less effect on mood (ϕNA→Rum and ϕRum→NA; $r = -0.046$), suggesting that when mood-linked rumination is present, any ruminative thinking occurring prior to that tends to have a smaller effect on mood.

Finally, the dynamic parameters were less intertwined for positive than negative affect, with only one significant association (see Fig. 2). Mean μPA and the cross-lagged coefficient PA→Rum were negatively correlated ($r = -0.171$), suggesting that greater rumination in response to decreased PA was associated with lower average levels of positive affect.

3.3. Habitual characteristics and the relationship between affect and rumination across time

For negative affect, HINT was significantly associated with larger cross-lagged parameters (ϕNA→Rum; B = 0.217; see Table 2). This relationship is depicted in Fig. 3 which shows that when associated with greater trait habitual characteristics, a momentary increase in NA is more likely to evoke heightened rumination on the next measurement occasion. This effect corresponds to an increase of 0.015 (absolute value) in the cross-lagged parameter ϕNA→Rum for each point increase in HINT.

Also, for positive affect, HINT was significantly associated with larger (negative) cross-lagged parameters (ϕPA→Rum; B = −0.304). Fig. 3 shows that, for PA, larger negative coefficients can be found at the

Table 2
Habitual characteristics of negative thinking (HINT) predicting the reciprocal association between momentary affect (NA/PA) and rumination (MRSI-A) over time. Standardized effects.

	Negative Affect				Positive Affect		
	B	SD	95% CI		B	SD	95% CI
Means				Means			
μ NA	5.02*	0.54	[4.04, 6.20]	μ PA	4.48*	0.39	[3.73, 5.28]
μ RUM	2.07*	0.20	[1.69, 2.47]	μ RUM	2.06*	0.20	[1.68, 2.45]
Autoregression				Autoregression			
ϕ NA→NA	0.35*	0.03	[0.30, 0.40]	ϕ PA→PA	0.43*	0.03	[0.37, 0.48]
ϕ RUM→RUM	0.26*	0.03	[0.20, 0.31]	ϕ RUM→RUM	0.30*	0.03	[0.24, 0.35]
Cross-lagged slopes				Cross-lagged slopes			
ϕ NA→RUM	0.12*	0.03	[0.06, 0.18]	ϕ PA→RUM	−0.08*	0.03	[-0.13, −0.03]
ϕ RUM→NA	0.05	0.03	[-0.01, 0.10]	ϕ RUM→PA	−0.03	0.03	[-0.09, 0.02]
Effect of HINT on…				Effect of HINT on…			
μ NA	0.35*	0.07	[0.20, 0.48]	μ PA	−0.20*	0.07	[-0.34, −0.05]
μ RUM	0.11	0.07	[-0.03, 0.25]	μ RUM	0.12	0.07	[-0.03, 0.26]
ϕ NA→NA	0.16	0.09	[-0.01, 0.33]	ϕ PA→PA	0.09	0.10	[-0.11, 0.29]
ϕ RUM→RUM	−0.04	0.09	[-0.20, 0.13]	ϕ RUM→RUM	−0.02	0.09	[-0.19, 0.15]
ϕ NA→RUM	0.22*	0.09	[0.03, 0.39]	ϕ PA→RUM	−0.30*	0.12	[-0.53, −0.08]
ϕ RUM→NA	0.09	0.11	[-0.12, 0.31]	ϕ RUM→PA	0.03	0.15	[-0.28, 0.32]
Variances				Variances			
$\Psi\mu$ NA	0.88*	0.05	[0.77, 0.96]	$\Psi\mu$ PA	0.96*	0.03	[0.88, 1.00]
$\Psi\mu$ RUM	0.98*	0.02	[0.94, 1.00]	$\Psi\mu$ RUM	0.98*	0.02	[0.93, 1.00]
$\Psi\phi$ NA→NA	0.97*	0.03	[0.89, 1.00]	$\Psi\phi$ PA→PA	0.98*	0.02	[0.92, 1.00]
$\Psi\phi$ RUM→RUM	0.99*	0.01	[0.96, 1.00]	$\Psi\phi$ RUM→RUM	0.99*	0.01	[0.96, 1.00]
$\Psi\phi$ NA→RUM	0.95*	0.04	[0.85, 1.00]	$\Psi\phi$ PA→RUM	0.89*	0.07	[0.72, 0.99]
$\Psi\phi$ RUM→NA	0.98*	0.03	[0.91, 1.00]	$\Psi\phi$ RUM→PA	0.98*	0.03	[0.88, 1.00]

**significance is based on the Credible Interval (CI) not containing zero.*
Note. RUM = Momentary rumination (MSRI-A), NA = Negative Affect, PA = Positive Affect.

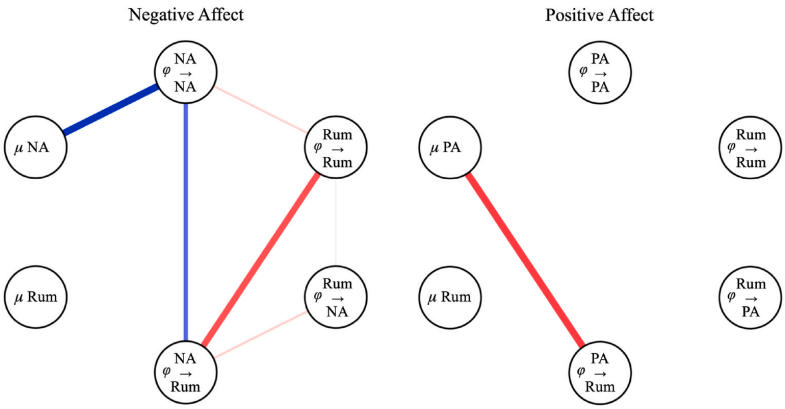

Fig. 2. The temporal relationship between momentary rumination (MRSI-A), negative affect (NA) and positive affect (PA). A visual representation of the correlations between means, autoregressive and cross-lagged parameters in the two models. Only correlations whose 95% credible interval did not include zero are included. Blue connections represent positive correlations and red connections represent negative correlations. The thickness of the lines indicate correlation strength. This correlation structure was created with qgraph in R (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

higher end of the HINT distribution, thus, *a decrease in PA* is more likely to evoke heightened rumination on the next measurement occasion when associated with greater habitual characteristics. This corresponds to a decrease of −0.007 (absolute value) in the cross-lagged parameter ϕPA→Rum for each point increase in HINT. As evidenced by the standardized estimates, this effect was larger for PA than for NA.

Finally, HINT was associated with higher average levels of NA (μ = 0.345) and lower average levels of PA (μ = −0.197), indicating that when accounting for the temporal relationships, heightened habitual characteristics were associated with greater levels of NA and lower levels PA over the course of the EMA assessment period. HINT was not significantly associated with other parameters in the models.

We followed these results with additional analyses to investigate the robustness of our findings. The current findings remained unchanged when the results were detrended to control for the possible influence of time on the measurements.[5] Ruminative brooding, when entered at the between level instead of HINT in the models above, was not a significant predictor of the cross-lagged parameter ϕNA→Rum (B = 0.125; 95% CI = [-0.05, 0.29]) nor ϕPA→Rum (B = 0.018; 95% CI = [-0.21, 0.25]). Depression symptoms (BDI-II), however, were predictive of a greater cross-lagged parameter for ϕNA→Rum (B = 0.195; 95% CI = [0.03, 0.36]) but not for ϕPA→Rum (B = −0.082; 95% CI = [-0.30, 0.15]).

HINT, ruminative brooding, and BDI-II were moderately correlated in the present study (see Table 1). We therefore computed the above

[5] The time of measurement was inserted in the within-part of the models to control for trends or non-stationary of the data during the measurement period. The results remained unchanged for both models of positive and negative affect.

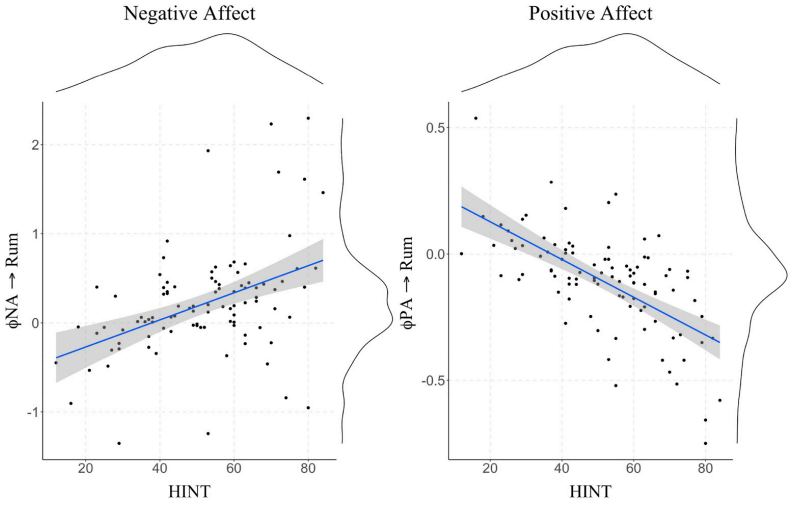

Fig. 3. Momentary negative (NA) and positive affect (PA) predicting rumination on the next measurement occasion given the individuals' habitual characteristics (HINT). Raw estimates of cross-lagged parameters ϕAffect→Rum for positive and negative affect are shown. Each dot corresponds to one participant. Marginal plots show density distributions for HINT and the cross-lagged parameters.

models again using the residual variance of HINT, when regressed on either ruminative brooding or BDI-II, to see whether the results depended on the shared variance between the measures. HINT (residualized by brooding) still remained a unique predictor of the cross-lagged parameters ϕNA→Rum (B = 0.154; 95% CI = [0.02, 0.31]) and ϕPA→Rum (B = −0.341; 95% CI = [-0.59, −0.10]). When accounting for depressive symptoms, HINT (residualized by BDI-II) still remained a unique predictor of the cross-lagged parameter ϕPA→Rum (B = −0.342; 95% CI = [-0.62, −0.09]) but not for ϕNA→Rum (B = 0.05; 95% CI = [-0.13, 0.24]).[6]

4. Discussion

The aim of the current study was to assess if the habitual characteristics of negative thoughts are related to the dynamic interplay between negative affect and ruminative thinking in the flow of daily life experiences. Momentary increased negative affect was prospectively associated with greater ruminative thinking at the next sampling occasion. This relationship was moderated by a measure of habitual characteristics of negative thinking, such that a stronger association was observed with greater levels of habitual characteristics (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness). To our knowledge, this is the first explicit test of habit-goal framework of depressive rumination using mobile EMA assessment. These key findings replicate previous results (Brose et al., 2015; Moberly & Watkins, 2008; Ólafsson et al., 2020) and extend them by showing that negative affect can trigger ruminative thinking in everyday life as a function of habit.

These findings are consistent with the habit-goal framework of depressive rumination (Watkins & Nolen-Hoeksema, 2014) which conceptualizes rumination as a response triggered by context (i.e., negative affect) rather than intentions or goals. Because habitual characteristics specifically predicted the degree to which individuals ruminated in response to negative affect, and not just average levels of momentary rumination, this suggests that depression vulnerability may be in the form of rumination being habitually triggered by contextual factors (without conscious awareness and intent), making it difficult to control. The results held when accounting for the shared variance of HINT with a cardinal measure of depressive brooding, indicating that HINT taps aspects of habitual rumination not fully captured by traditional trait measures of rumination. Although the brooding subscale of the RRS has often been considered a measure of habitual rumination, it focuses on the frequency of ruminative processing since respondents are asked to rate how often they have certain ruminative thoughts when they feel sad or depressed (rated on a scale of repetition from "almost never" to "almost always; Treynor et al., 2003). Although habitual behaviours may frequently emerge, frequency alone does not mean that behaviour is habitual in itself (Verplanken, 2006; Wood & Rünger, 2016). Behaviour that is repeatedly performed in a stable context, may gradually become a habit, that is controlled by contextual cues, rather than mediated by goals or intentions. Thus, habitual behaviours are also characterized by a degree of automaticity (i.e., lack of conscious awareness and deliberate intent, mental efficiency, and lack of control; Neal & Wood, 2009). HINT is aimed to measure both the automaticity and repetition of negative thinking (Verplanken et al., 2007) and should therefore be associated with a measure of the context-response association between affect and rumination if it has become habitual. Consistent with this, the current study found that HINT was as a significant predictor of the temporal pairing between affect and rumination whereas the brooding subscale of the RRS was not. In our view, this underlines the additive value of considering habit-like automaticity of thoughts in the study of adverse consequences of ruminative thinking in daily life.

Interestingly, although not specified by the habit-goal framework, the same pattern was found when assessing daily fluctuations in positive affect, showing that a deterioration of positive affect can also serve as a contextual trigger for ruminative thinking. Repeatedly experiencing *a decline* in positive affect whilst ruminating (e.g., when one's goals are persistently thwarted) might over time turn the deterioration of positive affect into trigger for subsequent rumination. Although this novel finding may suggest that the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) is relevant to a broader spectrum of emotional

[6] Full model results HINT (residualized) are provided in supplementary materials 3.

experiences, it should be interpreted with caution. Although negative and positive affect are assumed to be independent constructs (Watson et al., 1988), they are also strongly correlated (Green & Salovey, 1999). It may be that positive affect influences rumination partly through its overlap with negative affect. Using larger samples, it would be interesting to explore the relative contribution of negative and positive affect when investigating the habitual nature of depressive rumination. Furthermore, it can be argued that this finding might to some extent reflect the effects of positive rumination (i.e., savoring; see Li, Starr, & Hershenberg, 2017) which has been found to be associated with heightened levels of positive affect. However, a momentary decline in positive affect (rather than increased levels) was associated with greater rumination, that was associated with lower average levels of PA during the experience sampling period, indicating adverse effects of ruminative brooding rather than savoring effects of positive rumination.

According to the habit framework rumination only develops into a trait-like habit once negative affect and ruminative thinking are paired over time. It is therefore theoretically consistent to expect some to ruminate without engaging in habitual negative thinking and vice versa (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Consistent with this, we found significant variation in the degree to which habitual characteristics of negative thinking were associated with the context-response association between momentary affect and rumination.

Although not the main objective of the study, we also examined how our findings related to symptoms of depression severity. It is when rumination turns habitual that it is hypothesized to be more detrimental for people's emotional well-being (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Consistent with this, we found that people ruminate in response to daily fluctuations in negative mood as a function of depressive symptom severity. This suggests that once rumination has become contingent on the emotional context (i.e., negative affect) people also tend to experience more severe symptoms of depression. Furthermore, when accounting for the shared variance of HINT with depressive symptoms, habitual thinking was no longer a significant predictor of the temporal pairing between NA and subsequent rumination. Although we cannot exclude the possibility that this finding might to some extent reflect an overlap in negative content of the self-report measures, it is also in line with theoretical accounts of habitual rumination and might suggest that the link between habitual thinking and the dynamic interplay of affect-rumination at the microlevel overlaps with depressive symptomology in a meaningful way (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014). Interestingly, this pattern did not emerge when looking at decreased positive affect as a trigger for everyday rumination. Habitual negative thinking remained a significant predictor even when accounting for depressive symptomology, suggesting that it may represent a less maladaptive form of ruminative process, consistent with dimensional approaches to psychopathology (Kozak & Cuthbert, 2016). However, since depressive symptoms were not measured repeatedly over time in our study design, inferences of causality are precluded. Future studies should address this constraint using prospective designs, and specifically test whether the interplay between mood-triggered rumination and habitual thinking serve as predictors of depression status over time, confirming its role as a vulnerability factor (e.g., in groups with a recurrent history of depression).

Habitual characteristics of negative thinking were not associated with emotional inertia (i.e., more carry over of mood from one moment to the next). Although not directly related, HINT was associated with the degree to which negative affect triggered subsequent rumination, which in turn was associated with greater levels of emotional inertia, as well as less carry-over of rumination from one moment to the next (see Fig. 2). Although speculative, it is possible that an indirect relationship exists wherein habitual attributes facilitate greater mood-linked rumination, which in turn leads to heightened emotional inertia. In comparison, ruminating in response to deteriorating positive affect did not involve the same detrimental dynamic process of emotional inertia. This indicates that people recover relatively quickly when ruminating in response to decreased positive affect whereas when they ruminate in response to negative affect, they tend to get 'stuck' in their current negative emotional state. The finding that greater NA-linked rumination was associated with reduced carry-over of rumination, suggests that once rumination has become contingent on negative mood, it tends to vary more over time. Indeed, previous research has found momentary rumination to vary considerably over time (Moberly & Watkins, 2008) and recent findings suggest that a greater history of depression may be associated with more variable levels of rumination (i.e., less carry-over; Bean, Heggeness, Kalmbach, & Ciesla, 2020). This is line with the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) which posits that once habitual, negative mood states induced by processes other than perceived goal discrepancy could trigger rumination (e.g., watching a sad movie), extending the range of situations that cue ruminative thinking.

A particular strength of the study is the use of EMA assessment to capture rumination and affect in the flow of peoples' daily life experiences. This allowed us to test the effect of habitual characteristics on the temporal relationships between rumination and affect in an ecologically valid way (Myin-Germeys, 2018), which addresses limitations of previous studies (Verplanken et al., 2007; Ólafsson et al., 2020) restricted to trait measures of rumination. Crucially, we revealed a dynamic interaction between rumination and affect that would not have been apparent using trait measures alone.

This study also has limitations. Although we tested whether habitual characteristics influenced the strength of the temporal relationship between affect and rumination, the study does not address the developmental aspect of how rumination becomes habitual in the first place. According to the habit-goal framework (Watkins & Nolen-Hoeksema, 2014) situational factors that systematically thwart important goals and contribute to low mood (i.e., chronic stress and abuse) and person-specific factors associated with a lack of flexible responding (i.e., restricted coping repertoire and cognitive inflexibility) are hypothesized to facilitate the formation of rumination as a habit. Future research should aim to elucidate whether such situational and person-specific factors govern the strength the habitual association between affect and rumination. Furthermore, research should strive to assess whether the strength of the habitual association changes longitudinally as a function of such influencing factors. The EMA assessment methodology presented in the current study is ideally suited to test these novel predictions.

Another limitation has to do with the inference of causality. Although we found affect to influence rumination across time as a function of habit, it does not preclude other causal influences. Effect sizes in present study were generally moderate to small, indicating that other contributing factors might also cause affect to evoke a subsequent ruminative response. Further, there exist no reliable behavioural proxies to assess rumination as a habit. In the current study habitual qualities were inferred from self-report, limiting the inference of causality. Thus, the current findings highlight he need to clarify the unique role of habit in depressive rumination and the development of more specific behavioural measures of habitual rumination.

It must also be noted that although participants were specifically instructed to answer EMA questions in the moment based on how they felt just prior to the alert, the order in which EMA questions were presented was fixed. Items pertaining to affect were presented first preceding the rumination items, which could potentially prime a response for the rumination questions. Future research should address this potential shortcoming by utilizing varied or randomized item order designs.

Although the current study consisted of participants with a wide range of depression symptomology, it is unclear whether clinical depression differs dimensionally or categorically from non-clinical depression (Hankin, Fraley, Lahey, & Waldman, 2005). It is therefore

unclear if our findings would generalize to samples of individuals with a history of clinical depression. Majority of the sample were female students, limiting the generalization of the findings to males. We are working on replicating the current findings using a variety of experimental measures (see e.g. Hjartarson et al., 2020) and EMA assessment of rumination in diverse samples, including a history of clinical depression.

Our findings should be viewed in the context of the clinical relevance of the habit account of depressive rumination (Watkins & Nolen-Hoeksema, 2014). Interventions that modify individuals' beliefs and attitudes are unlikely to change habitual behaviours (Webb & Sheeran, 2006). Therefore, they may not be effective at changing habitual rumination, which could explain why rumination predicts a poorer response to standard cognitive-behavioural therapy (CBT; Jones & Siegle, 2008; Schmaling, Dimidjian, Katon, & Sullivan, 2002). Given that rumination has become contingent on the emotional context (i.e., negative or positive affect), preventive and acute therapy of depression needs to target the context-response association between affect and rumination, not just the *content* of the ruminative thoughts. The ruminative response needs to be replaced with a more helpful way of responding (e.g. concrete thinking, mindfulness, relaxation) to develop new context-response associations (Watkins & Nolen-Hoeksema, 2014; Wood & Neal, 2007).

Promising interventions include cognitive bias modification (CBM; Hertel, Holmes, & Benbow, 2014) and rumination-focused CBT (Watkins, 2018), that involve repeated training of alternative adaptive responses when faced with emotionally challenging situations. The findings of this study could be used to inform case conceptualization and treatment selection in future studies on the subject. We hypothesize that individuals with greater habitual rumination should respond more favorably to interventions such as CBM and rumination-focused CBT compared to individuals with less habitual rumination. Importantly, the EMA measurement strategy utilized in the current study could be used to test whether interventions are successful in reducing the habitual characteristics of the association between affect and rumination. This may provide information on the mechanisms of change during therapy and the predictive value of utilizing EMA measurement approaches in studying psychological well-being (see e.g. Dejonckheere et al., 2019).

5. Conclusion

The present results suggest that depression vulnerability may be in the form of rumination being habitually triggered in response to momentary fluctuations in affect, consistent with the habit-goal framework of depressive rumination (Watkins & Nolen-Hoeksema, 2014). Rumination may also be more detrimental when habitual because it leads to a greater persistence of dysphoric mood (i.e., emotional inertia) and more fluctuating levels of ruminative responding. To our knowledge, this is the first study to assess the role of habitual characteristics in the dynamic interplay between rumination and affect in daily life using EMA methodology. Our findings begin to outline how habits may emerge as a dynamic relationship between rumination and affect across time, that would not have been revealed with traditional trait measures alone. We hope that future research will expand on these findings and explore if assessing and targeting the habitual attributes of ruminative thinking can inform treatment selection and boost treatment response, thereby reducing suffering and depression vulnerability.

CRediT authorship contribution statement

Kristján Helgi Hjartarson: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Ivar Snorrason:** Conceptualization, Writing – review & editing, Funding acquisition, Supervision. **Laura F. Bringmann:** Methodology, Formal analysis, Writing – review & editing, Supervision. **Bjarni E. Ögmundsson:** Software. **Ragnar P. Ólafsson:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition, Supervision, Project administration.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2021.103832.

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Paper III

Automaticity and Depression: Daily Mood-Reactive Rumination in People With- and Without Depression History

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Abstract

Depressive rumination has been conceptualized as a mental habit that is initiated automatically without conscious awareness, intent, or control in response to negative mood. However, it is unknown whether depression vulnerability is characterized by elevated levels of mood-reactive rumination at the level of short-term dynamics. Using mobile ecological momentary assessment, formerly depressed individuals with a recurrent history of depression (n = 94) and non-clinical controls (n = 55) recorded *in-the-moment* affect and rumination ten times daily over six days, after completing baseline measures of trait ruminative brooding, early-life stress, and habitual characteristics of negative thinking (e.g., automaticity, lack of conscious awareness, intent, and control). Momentary fluctuations in negative affect were prospectively associated with greater rumination at the next sampling occasion in formerly depressed participants whereas this pattern of mood-reactive rumination was not observed in non-clinical controls. In formerly depressed participants, habitual characteristics of negative thinking was associated with greater mood-reactivity of rumination, particularly among those with a history of early life-stress. Mood-reactive rumination was not, however, associated with depression course nor with the frequency of trait ruminative brooding. Rumination may be triggered in response to negative affect with a high degree of automaticity, making it difficult to control. Greater mood-reactivity of rumination might be associated with increased depression risk, independent of the depressive course and may be exacerbated by early-life stress. Future studies may need to go beyond frequency and focus on the role of mood-reactivity and automaticity of ruminative thinking in depression vulnerability.

Keywords: Depression; Rumination; Habit; Ecological Momentary Assessment; Early-life stress.

General Scientific Summary

Ruminating when feeling sad is a risk factor for episode onset in major depressive disorder, yet rumination is frequently measured at a single point in time in the experimental setting not capturing the interaction between affect and cognition in daily life. The results of this experience sampling study revealed a dynamic temporal pairing between negative affect and subsequent state rumination in formerly (but not in never) depressed people, that were at increased risk of future depression episode. Mood-reactive rumination was characterised by increased automaticity of negative thoughts, moderated by early life stress, but not captured by traditional measures of trait rumination. Identifying daily ruminative habits and their distal causal factors will inform theory of cognitive vulnerability to depression recurrence and selection of prevention and treatment strategies.

Efforts to identify indicators of depression risk have strongly implicated depressive rumination, a negative thinking style characterized by repetitive and passive thoughts about the causes, meanings, and consequences of one's feelings and distress (Nolen-Hoeksema et al., 1991). The Response Styles Theory (Nolen-Hoeksema, 1991), the principal theory of depressive rumination, defines rumination as an enduring and stable *habitual-like* cognitive response to sad mood. This suggests that mental habits may underpin a persistent disposition to ruminate following negative mood. Rumination has indeed been described as a mental habit in the depression literature (e.g., Hertel, 2004) and more recent theoretical frameworks of depression vulnerability continue to emphasize the role of habit in depressive rumination (see e.g., Shaw et al., 2019). Although the role of trait rumination has been extensively studied in the onset of both first and recurrent episodes, as well as episode maintenance in depression (Nolen-Hoeksema et al, 2008), it is still unclear if elevated mood-reactive rumination at the level of short-term dynamics characterizes those at increased risk for episode onset. Only few studies have addressed the temporal interplay between negative affect (NA) and rumination on shorter time scales, from moment to moment, as described by the Response Styles Theory and more recent theoretical accounts of habitual rumination (e.g., Watkins & Nolen-Hoeksema, 2014). The current study aims to address this gap by utilizing Ecological Momentary Assessment to better understand the dynamic interplay between NA and rumination in daily life in individuals at high risk of experiencing future depressive episodes.

Rumination as a Mood-Reactive Mental Habit

An increasingly popular theoretical perspective posits that depressive rumination is a mental habit that is initiated automatically without conscious awareness or intent in response to downward shifts in mood, making it persistent and difficult to control (Farb et al., 2015; Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). Habits are behaviours that occur frequently and unintentionally (Orbell & Verplanken, 2010). They are formed by learned associations between behavioural responses and their performance contexts. Once formed, context cues become automatic triggers for the behaviour, such that it is controlled solely by the presence of the context cues (Wood & Neel, 2007). Thus, habits are characterized by a degree of automaticity (e.g, lack of conscious awareness and deliberate intent, mental efficiency, and lack of control; Verplanken et al., 2007).

According to habitual accounts of rumination, transient episodes of ruminative thinking are thought to arise in response to perceived discrepancies between desired states and present reality. This process is considered adaptive when rumination facilitates progress towards desired states, however, when goals are repeatedly not reached, rumination persists, and mood deteriorates (Watkins, 2008). The consistent use of passive and abstract ruminative thoughts to cope with such persisting discrepancies cause NA and ruminative thinking to be paired over time, turning rumination into a habit triggered by context (i.e., NA) rather than intentions (Watkins & Nolen-Hoeksema, 2014). Person-specific factors that contribute to a lack of flexible responding and situational factors that systematically thwart important goals may serve as potential risk factors for transient episodes of rumination to consolidate into a habitual style of thinking (Shaw et al., 2019; Watkins & Roberts, 2020).

Personally important goals may be chronically thwarted in abusive and stressful environments, generating repeated episodes of goal-discrepancy thoughts contingent on negative mood (Watkins & Nolen-Hoeksema, 2014). Stressful early-life events, particularly a history of physical, sexual, and emotional abuse, predict elevated levels of rumination in adulthood (LeMoult et al., 2019) and rumination, in turn, has been found to mediate the relationship between childhood abuse and depression severity later in life (McLaughlin & Hatzenbuehler, 2009).

Empirical Support for Habitual Accounts

The brooding subscale of the Response Style Questionnaire (RRS; Nolen-Hoeksema, 1991; Treynor et al., 2003) has often been considered a measure of habitual rumination, and numerous studies have found elevated levels of brooding in currently and remitted depressed individuals compared to non-clinical controls (reviewed in Aldao et al., 2010). However, the RRS only assesses the *frequency* of rumination in response to low mood (rated on a scale of repetition from "almost never" to "almost always; Treynor et al., 2003) and does not assess other key characteristics of habits as automatically triggered behavioural responses (e.g., initiated without awareness, unintended, and difficult to control; Watkins & Roberts, 2020).

Some preliminary evidence exists for the rumination as-a-habit account. In a novel simulation study, Van Vugt et al. (2018) showed that modelling rumination as-a-habit best predicted the impairments of depressed participants on a sustained attention task. Verplanken et al. (2007) also found that in a sample of university

students rumination was strongly correlated with the Habit Index of Negative Thinking (HINT) - a self-report measure of the habitual characteristics of negative thoughts (i.e., repetition, lack of conscious awareness and deliberate intent, mental efficiency, lack of control and self-descriptiveness). Ólafsson et al. (2020) found that habitual characteristics of self-focused thoughts were elevated in formerly depressed individuals, compared individuals with no depression history. Ruminative brooding was found to be associated with increased habitual characteristics, whereas this relationship was not evident for ruminative reflection, often considered a more adaptive form of rumination (Ólafsson et al., 2020). Habitual characteristics of self-focused thoughts may also be associated stronger emotional response following experimental induction of brooding-like thinking style. Hjartarson et al. (2020) found, in a student sample, that higher scores on HINT were associated with slower return to baseline of negative emotions following induction of analytical and brooding-like thinking style frequently used in experimental studies (see Nolen-Hoeksema et al., 2008; Rimes & Watkins, 2005).

Although promising, these findings are limited in several ways. First, because rumination is measured at the trait level, at a single time-point and averaged across time, they may not apply to state fluctuations in affect and rumination. Second, rumination is measured with self-report, by asking respondents to think back to a time when they felt sad, increasing the probability of retrospective bias. Additionally, inducing rumination by asking participants to focus on a standardized battery of rumination-like questions may not generalize to habitual rumination automatically cued in daily life. Finally, previous studies did not address the hypothesized temporal

context-response association between affect and rumination, rendering causal inference impossible.

One way to address these shortcomings is to use more ecologically valid assessment procedures, such as Ecological Momentary Assessment (EMA), to capture the interplay between affect and rumination in the flow of daily life experiences. The longitudinal nature of EMA makes it ideally suited to examine temporal relationships between context and behaviour on the microlevel (Myin-Germeys, 2018) and provides the basis for testing dynamic models empirically that has been missing so far. Studies using EMA in student samples have revealed a reciprocal relationship between affect and rumination at the level of short-term dynamics, with rumination predicting subsequent changes in NA, and NA predicting changes in rumination to the same effect (Blanke et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008). Addressing the potential habitual nature of rumination more directly, Hjartarson et al. (2021) studied daily fluctuations in mood and rumination during a six-day experience sampling period in a sample of 97 university students with a wide range of depressive symptoms. Participants also completed questionnaire measures of habitual characteristics (HINT) and ruminative brooding (RRS). Momentary increased NA predicted greater subsequent rumination at the next sampling occasion when associated with heightened levels of habitual characteristics - a finding that was only partially accounted for by trait levels of ruminative brooding. However, the moderating role of habitual characteristics was fully accounted for by current symptoms of depression, suggesting that, when habitual, mood-reactive rumination coincides with concurrent depression symptomology.

Aims of the Current Study

The current study aimed to provide a test of the presumed mood-reactive nature of rumination. Habitual characteristics of negative thinking characterise euthymic formerly depressed, compared to healthy controls, and predict a stronger dynamic interplay between NA and daily rumination that overlaps with increased symptoms of depression in non-selective samples. This is in line with the theoretical framework of rumination as a persistent habit that confers risk for depression (Watkins & Roberts, 2020). We are not aware, however, of any EMA study that directly tests the assumption that individuals at increased risk of depression demonstrate elevated mood-reactive rumination in daily life. If habit-like triggering of daily mood-reactive rumination predisposes people to the onset of depression episodes, it should be observed in at-risk samples in a euthymic state and be unconfounded with current symptoms (e.g. Ingram et al., 2011). The current study was conducted in a sample of euthymic participants with a history of recurrent depression, and therefore at increased risk of future depression episode (e.g., Buckman et al., 2018). A low depression-risk group of euthymic non-clinical controls was recruited to serve as a comparison. We made two predictions derived from the theoretical framework of habitual rumination (Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020) and prior findings (Blanke et al., 2021; Hjartarson et al., 2021; Moberly & Watkins, 2008; Ólafsson et al., 2020).

H1. We expected formerly depressed individuals to demonstrate considerable mood-reactive rumination in daily life, such that momentary increased NA would prospectively predict greater rumination-levels at the next sampling occasion. However, we expected that mood-reactive rumination would not be apparent in more resilient healthy controls with no depression history.

H2. It is when depressive rumination turns habitual that it is thought to be triggered to a greater extent in response to negative mood. We therefore expected the degree of mood-reactive rumination in daily life of formerly depressed participants, to be moderated by habit, with heightened habitual characteristics of negative thinking predicting greater rumination in response to momentary fluctuations in NA.

To our knowledge, this is the first direct empirical test of the proposed mood-reactivity of rumination in the daily life of individuals with a history of depression. We followed these hypotheses with a number of exploratory analyses. As mentioned previously, early-life stress might serve as a catalyst for habitual rumination through more systematic pairing between episodes of state ruminative thoughts and negative mood (Shaw et al., 2019; Watkins & Roberts, 2020). Furthermore, it is reasonable to expect rumination, that has consolidated as a persistent habit, to be associated with a more severe course of depression. We therefore explored if early-life stress, particularly a history of physical, sexual, or emotional abuse, and depression course (number of episodes, age of onset and stability of remission) was associated with greater mood-reactive rumination.

Method

Participants

Data were consecutively collected as a part of a randomized controlled trial (for preregistration see isrctn.com: No. 92714827). The current study is based on data collected at baseline prior to treatment. Ethics approval was attained from the National Bioethics Committee, the Bioethics Committee of the Primary Health Care, and reviewed by the Icelandic Data Protection Authority (protocol number VSN-235). Recurrent formerly depressed participants (RFDs) were recruited via referrals from general practitioners and mental health specialists in primary care centres, as well as through public advertisements, to participate in a trial on the efficacy of Mindfulness Based Cognitive Therapy (MBCT) for recurrent depression. Inclusion criteria included an age between 18 and 65 years and a history of three or more major depressive episodes but currently in remission. Exclusion criteria included a current major depressive episode and moderate or severe depression symptoms (a score >19 on the BDI-II; Beck et al., 1996). Non-clinical controls (NCs) were simultaneously recruited through public advertisements. Inclusion criteria included an age between 18 and 65 years and a score of 19 or lower on the BDI-II. Exclusion criteria included a presence or history of mental disorders. Detailed description of participant recruitment and inclusion criteria is provided in the online supplementary materials A.

Measures

Lifetime history of depressive episodes and psychiatric diagnoses. The MINI-International Neuropsychiatric Interview (MINI; Sheehan et al., 1998) was used to obtain psychiatric diagnoses. MINI is a semi-structured interview for the most common Axis I disorder of the DSM-IV. The Icelandic version was administered for which adequate validity has been demonstrated (Kristjánsdóttir et al., 2015; Sigurðsson, 2008). The present study utilized a composite version of MINI with the depression module from MINI-Plus but with other modules from the standard MINI. Based on Ólafsson et al. (2020) questions were added to assess the number of past depressive episodes, age of onset, and the stability of remission. After confirming the presence of a past major depressive episode, participants were asked how often they had experienced such an episode and to indicate when each episode had started and when it ended. Only episodes of adequate duration (2 weeks or more) that caused significant functional impairment and were separated by periods of remission (at least 2 months) were included. Participants also indicated if they had experienced one or both core symptoms (depressed mood/anhedonia) in the past eight weeks, but with a shorter duration of at least one week. If endorsed, they were inquired about other potential symptoms using the same criteria. Stability of remission was defined as the total number of subclinical symptoms. We recorded audio from all MINI interviews. A sample of 22 recordings (approx. 20%) was randomly selected for reassessment by an independent researcher. Interrater reliability between the original evaluation and reassessment was .92, 95% CI = [0.96, 0.99] for number of previous episodes and .91, 95% CI = [0.78, 0.96] for age of onset. All participants sampled were found to

have a history of at least 3 previous episodes but currently in remission with perfect agreement between raters.

Beck Depression Inventory (BDI-II). The BDI-II is a 21 item self-report questionnaire that measures the severity of depression symptoms during the past two weeks (Beck et al., 1996). The Icelandic versions (Arnarson et al., 2008) has shown good psychometric properties. The BDI-II had an $\alpha = 0.87$ in the current study.

The Ruminative Responses Scale (RRS). The RRS is a self-report measure of ruminative disposition which contains 22 items that assess a person's tendency to think about the symptoms, causes, and consequences of their depressed mood (Nolen-Hoeksema & Morrow, 1991). The current study utilized the 5-item brooding subscale (RRS-B), which measures more passive, analytical and repetitive forms of thinking, and is thought to represent the maladaptive component of rumination (Treynor et al., 2003). The Icelandic version has shown good psychometric properties (Pálsdóttir & Pálsdóttir, 2008). In the current study RRS-B had an $\alpha = 0.81$.

Habit Index of Negative Thinking (HINT). The habitual quality of negative thinking was measured with the HINT (Verplanken et al., 2007), a 12 item self-report scale that measures the degree to which self-focused negative thoughts occur frequently, are initiated without awareness, are unintended, are difficult to control, and are self-descriptive. Each item is rated on a 7-point scale in response to the general prompt; "Thinking negatively about myself is something…". and included items such as "I do unintentionally" and "I start doing before I realize I'm doing it".

The Icelandic version has shown high internal consistency and good discriminant validity (Ólafsson et al., 2019). In the current study HINT had an $\alpha = 0.96$.

Early-life stress. The Childhood Traumatic Events Scale (CTES; Pennebaker & Susman, 1988) was used to assess participants' history of early-life stress before the age of 17. Participants were asked whether they had experienced certain stressful events, the age at which they experienced them (not reported here), how traumatic the event had been on a 7-point scale (1 = not at all traumatic, 7 = extremely traumatic). Events included: Physical abuse, mugging or assault; sexual abuse or molestation; major parental conflicts; death of a family member or person very close to the child; severe illness or injury; and other traumatic events which were perceived to impact the individual's personality or life trajectory. An additional item to assess history of emotional abuse was added in the present study; "Prior to the age of 17, did a parent or other household member frequently swear at you, degrade or humiliate you?" based on questions in other well-established measures of adverse childhood experiences (e.g., the ACE scale; Felitti et al., 1998). The CTES yielded a cumulative score, by summing the number of stressful early-life events, and a total severity score, calculated by summing the severity of each reported event. The CTES demonstrates good reliability and validity (Pennebaker & Susman, 1988) and sensitivity to clinical symptoms following early life stress, including PTSD and depression (Scheller-Gilkey et al., 2004).

Momentary mood ratings. Participants rated their current mood at each alert during the EMA period. The choice of items was based on the widely used Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) and previous EMA

studies (revealing items with high loadings on NA; e.g., Wichers et al., 2012). NA consisted of the following items: 1) *I feel sad right now*, 2) *I feel irritable right now*, and 3) *I feel guilty right now*. Participants responded using a five-point scale from 1 (Not at all) to 5 (Very much). NA had an $\alpha = 0.97$ at the between-level and $\alpha = 0.54$ at the within-level and was strongly correlated with BDI-II ($r = 0.53$)[8].

Momentary rumination. An abbreviated form of the Momentary Ruminative Self-Focus Inventory (MRSI-A; Connolly & Alloy, 2017; Hjartarson et al., 2021) was chosen for use during the EMA period which contained three items: 1) *Right now, I am thinking about how happy or sad I feel*, 2) *Right now, I wonder why I react the way I do*, and 3) *Right now, I am thinking about the possible meaning of the way I feel*. Participants indicated their degree of rumination at the time of the alert using a 7-point scale, from 1 (Strongly disagree) to 7 (Strongly agree). The MSRI-A has shown excellent internal consistency and is correlated with alternative measures of rumination (Connolly & Alloy, 2017) and has been found to be sensitive to changes in response to experimental manipulations of depressive rumination (e.g., Grol et al., 2015; Hertel et al., 2014). The MSRI-A had an $\alpha = 0.98$ at the between-level and $\alpha = 0.83$ at the within-level and was moderately correlated with RRS-B ($r = 0.33$)[1].

[8] Correlations are based on within-person averages of NA and MSRI-A

Procedure

Baseline assessment. Participants partook in a 2-hour in-laboratory session. Participants completed self-report questionnaires and were briefed one-on-one on the EMA procedure by a research assistant following a standardized research protocol. The EMA items were explained by a research assistant, exemplifying the meaning of each item and answering any questions. Participants then reviewed a sample EMA alert with the researcher to ensure proper understanding of the smartphone app and the sampling procedure.

EMA assessment. Beginning the following day after the in-lab assessment, participants were prompted by the smartphone app to answer 10 alerts per day for six consecutive days during a 12-h period (between 10 a.m. and 10 p.m.). Alerts were programmed according to a stratified semi-random interval scheme. Each day was divided into ten 72-minute intervals, with a signal occurring randomly within each interval, with an average of 92-minutes between alerts. Each time, participants gave their momentary rating of NA and rumination. Participants were instructed to answer given how they felt and thought "in-the-moment" just before the alert and to complete the measures immediately upon receiving an alert. After receiving an alert, participants had 25 minutes to respond before it expired. Alerts were presented and responses collected using The Experience Sampler App (Thai & Page-Gould, 2017) an open-source app for EMA research (www.experiencesampler.com).

Debriefing. Upon completing the EMA period, participants returned to the laboratory where they were debriefed and received compensation for their participation (Approx. €30).

Statistical Analyses

Analyses were conducted in Mplus version 8.5 (Muthén & Muthén, 2017) and in R version 4.0.3 (R Core Team, 2020) using the packages *ggplot2* for data visualization (Wickham, 2009) and *psych* for estimating multilevel reliability (time nested within people) and to calculate mean squared successive difference scores (MSSDs), which provide the average magnitude of each person's moment-to-moment fluctuations in NA and rumination (Revelle, 2020). Participants with fewer than 12 out of 60 (20%) completed alerts were excluded from the analyses. Previous research has shown that EMA assessment with less than 30% completed alerts may be unreliable (Delespaul, 1995). The same pattern of findings was observed when using a more conservative criteria of at least 20 out of 60 valid alerts. We therefore present results based on a more inclusive sample in our analyses. Given the nested structure of the data (repeated assessments within individuals) we utilized Dynamic Structural Equation Modelling (DSEM) in Mplus, a multilevel approach to analysing EMA data (Hamaker et al., 2018). Using DSEM we fitted cross-lagged models to investigate the dynamic relationship between momentary affect and rumination. The models were run using Bayesian estimation with non-informative priors. We used 50.000 iterations on two independent Monte Carlo Markov Chains, of which every 10^{th} was recorded for estimation purposes. A Bayesian approach is used in DSEM because it allows for the simultaneous estimation of multiple outcome variables and their covariances and the accurate modelling of time-series data with unequal intervals between measurement occasions (Schuurman et al., 2016). We provide standardized results for within-person and between-person effects. All continuous between-level variables were grand-mean centered. Statistical significance is based

on the credible interval not containing zero (the default in DSEM). The corresponding Mplus code is included in the supplementary materials B.

Hypothesis 1: Group differences in mood-reactive rumination in the daily life of RFDs and NCs. To test our hypothesis that momentary fluctuations in NA predict subsequent rumination in RFDs but not NCs, three successive models were computed. A visual representation of the models is shown in Figure 1.

[Figure 1 about here]

We first modelled the within-person relationships between momentary NA and rumination for each group separately to estimate significant paths within each group (Figure 1a). NA and rumination at any given time-point (*t*) were predicted by NA and rumination at the previous time-point (*t-1*). We were interested in the effect of the variables on themselves (autoregressive paths) and on each other (cross-lagged paths). These associations were allowed to differ between individuals (i.e., random means and slopes). We follow Hamaker and colleagues (2018) in presenting our models. The models decompose affect and rumination into latent within- and between-person components. The within-person components describe affect and rumination of individual *i* at time *t*:

$$\begin{aligned} Affect_{it} &= \mu_{NA,\,i} + \varphi_{1i}\, NA^{(w)}_{it\text{-}1} + \varphi_{3i}\, Rumination^{(w)}_{it\text{-}1} + \zeta_{1it} \\ Rumination_{it} &= \mu_{Rumination,\,i} + \varphi_{2i}\, Rumination^{(w)}_{it\text{-}1} + \varphi_{4i}\, NA^{(w)}_{it\text{-}1} + \zeta_{2it} \end{aligned} \qquad \text{(eq. 1)}$$

where $\mu_{Affect,\,i}$ and $\mu_{Rumination,\,i}$ are the time-invariant (between-person) means of affect and rumination for individual *i.* The autoregressive parameters $\varphi_{1i \text{ and } } \varphi_{2i}$ represent the effect of the variables at *t-1* on themselves at time *t.* The cross-lagged parameters $\varphi_{3i \text{ and } } \varphi_{4i}$ are the effects of the variables at *t-1* on each other at time *t*. The parameters ζ_{1it} and ζ_{2it} represent the residual variation at time-point *t* not explained by rumination and affect at the previous time-point *t*-1. Both the means μ_i and the lagged parameters φ_i are allowed to vary across individuals (hence the subscript *i*). Scores were latent person-mean centered to better capture fluctuations in NA and rumination relative to individuals' mean levels during the assessment period (the default in DSEM; Asparouhov et al., 2018)

Using the whole sample, we then estimated the effect of group membership on the between-level (see Figure 1b) on the autoregressive and cross-lagged parameters on the within-person level (dichotomous; 1 = RFDs, 0 = NCs):

$$\begin{aligned} \mu_{NA,\,i} &= \gamma_{00} + \gamma_{01}\,\text{Group}_i + u_{0i} \\ \mu_{Rumination,\,i} &= \gamma_{10} + \gamma_{11}\,\text{Group}_i + u_{1i} \\ \varphi_{1i} &= \gamma_{20} + \gamma_{21}\,\text{Group}_i + u_{2i} \\ \varphi_{2i} &= \gamma_{30} + \gamma_{31}\,\text{Group}_i + u_{3i} \\ \varphi_{3i} &= \gamma_{40} + \gamma_{41}\,\text{Group}_i + u_{4i} \\ \varphi_{4i} &= \gamma_{50} + \gamma_{51}\,\text{Group}_i + u_{5i} \end{aligned} \qquad \text{(eq. 2)}$$

where $\gamma_{00\text{-}50}$ is the fixed average of the parameters and u_i is the individual deviations from these effects. On the between-level, group membership, denoted as γGroup, was included as a predictor of the person-specific means and person-specific autoregressive and cross-lagged associations. All parameters were allowed to covary.

Hypothesis 2: Habitual characteristics predict mood-reactive rumination in daily life of RFDs. To test whether habitual characteristics (HINT) was a predictor of mood-reactive rumination in RFDs, we computed the cross-lagged model (Figure 1) using HINT instead of group membership as our between-level predictor (eq. 2) of the autoregressive and cross-lagged associations between NA and rumination on the within-person level (eq. 1). If fluctuations in NA trigger subsequent ruminative thinking as a function of habit, stronger φNA→Rum associations should be associated with greater habitual characteristics (HINT).

Exploratory analyses: The role of depression course and early-Life stress in mood-reactive rumination in daily life of RFDs. We also explored if mood-reactive rumination in RFDs was associated with the depression course (age of onset, number of episodes, stability of remission) and history of early-life stress (cumulative early-life stress, perceived stress severity, and history of abuse (physical, sexual, or emotional). We first computed the cross-lagged model (Figure 1) in RFDs and entered each exploratory variable individually on the between-level (eq. 2), as predictors of the autoregressive and cross-lagged associations on the within-person level (eq. 1). We then explored whether the effect of each variable was moderated by habitual characteristics (HINT) by simultaneously entering each individual variable (γVAR) along with HINT on the between-level as well as adding an interaction term HINT*γVAR, created by multiplying each variable by scores on HINT (no

correction for multiple testing). Due to the low number of RFDs reporting 4 or more stressful early-life events, they were collapsed into one category, resulting in cumulative stress scores between 0 and 4. When analysing the models for subgroups events were dummy coded (1 = history of abuse, 0 = no history of abuse).

Result

Sample Characteristics

A total of 103 RFDs were included in the trial, of which 94 (19 men, 75 women) provided sufficient EMA data (≥20%) to be included in the analyses. In total 55 NCs (12 men, 43 women) were recruited, all of which provided adequate EMA responding. See Table 1 for details on the characteristics of both samples. RFDs had experienced an average of 7.1 (*SD* = 3.6) lifetime depressive episodes and mean age of first-episode onset was 18.1 (*SD* = 6.9) years. There were no significant differences between the groups concerning age (mean age of 36.8 vs 39.7), gender, relationship status, educational level, or current employment status. As might be expected, RFDs worked somewhat lower percentages compared to NCs. On average, RFDs reported a greater number of stressful early-life events and were more likely to have a history of abuse. RFDs also showed higher levels of depression (BDI-II), habitual-characteristics (HINT) and trait levels of brooding (RRS-brood). Non-completers (those who did not provide a sufficient number of responses) did not significantly differ from the sample with regards to age, gender ratio, relationship status, educational level, or employment status (See supplementary materials G).

Preliminary Analyses of EMA Data

Participants completed a total of 6008 EMA alerts (RFDs =3733, NCs = 2275). RFDs completed on average 66% (range = 20%-93%) of the EMA alerts compared to 69% (range = 20% - 95%) in the NCs, with no-significant difference between the groups, $t(107.5) = 0.86$, $p = 0.394$. Across time, ratings of momentary NA were significantly higher in RFDs ($M = 4.27$, $SD = 0.98$) than in NCs ($M = 3.28$, $SD = 0.32$), $t(123.3) = 9.02$, $p < .001$. In addition, RFDs demonstrated more moment-to-moment fluctuations in NA ($MSSD = 2.67$, $SD = 2.76$) compared to NCs ($MSSD = 0.87$, $SD = 1.14$), $t(135) = 5.58$, $p < .001$. The groups did not differ in their average level of momentary rumination ($M = 6.87$, $SD = 3.14$, in RFDs vs. $M = 6.10$, $SD = 3.57$, in NCs), $t(101.7) = 1.34$, $p = .185$. However, RFDs showed more pronounced moment-to-moment fluctuations in rumination ($MSSD = 16.61$, $SD = 12.21$) compared to NCs ($MSSD = 6.81$, $SD = 8.12$), $t(144.5) = 5.87$, $p < .001$. Mean levels of NA and rumination did not change as a function of time during the EMA assessment period[9]. Between-person correlations of trait and EMA measures are provided in supplementary materials H.

[9] There were no significant trends for either group in momentary levels of NA or rumination. No effects were found for the time of day (start and end of day), day of EMA, or time of measurement. The current results remained unchanged when time of measurement was inserted in the within-part of the models to control for trends or non-stationary of the data during the EMA assessment period.

[Table 1 about here]

Hypothesis 1: Group Differences in Mood-Reactive Rumination in the Daily Life of RFDs and NDs

The effect of group on the temporal associations between NA and rumination is presented in Figure 2 and their corresponding paths are visualized in Figure 1. Detailed model results are provided in supplementary materials C and D. Group was a significant predictor of mood-reactive rumination (Group on φNA→Rum) during the EMA assessment period (B = 0.247, SD = 0.10, 95% CI = [0.04, 0.45]). The cross-lagged association between NA and subsequent rumination was significant in RFDs (φNA→Rum; B = 0.086, SD = 0.02, 95% CI = [0.04, 0.13]) but not in NCs (B = -0.005, SD = 0.05, 95% CI = [-0.09, 0.09]), when controlling for both initial levels of rumination and the effect that rumination had on subsequent mood[10]. Mood-reactive rumination did not change as a function of time in either group during the

[10] It should also be noted that the contemporaneous association between NA and rumination was stronger in RFDs (B = 0.197, SD = 0.02, 95% CI = [0.16, 0.23]) than in NCs (B = 0.171, SD = 0.02, 95% CI = [0.13, 0.21]) although both groups demonstrated a significant relationship.

EMA period[11]. Given the significant difference between groups in current depressive symptoms (see Table 1), we entered BDI-II and group membership simultaneously on the between-level, to control for possible confounds with current depressive status. Group membership still remained a significant predictor of greater mood-reactive rumination (Group on φNA→Rum; B = 0.260, SD = 0.12, 95% CI = [0.17, 0.51]). Group also emerged as a significant predictor of the cross-lagged association between rumination and subsequent NA (see Figure 2; Group on φRum→NA; B = 0.148, SD = 0.06, 95% CI = [0.03, 0.27]), with increased rumination leading to greater subsequent levels of NA (φRum→NA) in RFDs (B = 0.038; SD = 0.01, 95% CI = [0.02, 0.06]) but not in NCs (B = -0.022; SD = 0.03, 95% CI = [-0.08, 0.05]).

[Figure 2 about here. In colour]

[11] Additional models found no effect for time of day, day of EMA, or time or measurement on mood-reactive rumination (all credible intervals contained zero). These were run using a cross-classified extension of the the two-level model that seperates the between-level into person-specific and time-specific effects, which is needed for the analysis of trends in between-level latent variables (see Asparouhov et al., 2018).

Hypothesis 2: Habitual Characteristics Predict Mood-Reactive Rumination in Daily Life of RFDs

To test whether mood-reactive rumination is associated with habitual characteristics of negative thinking (HINT), a cross-lagged model using HINT as a between-level predictor was tested in RFDs where NA was shown to be a significant predictor of rumination across time. HINT was significantly associated with larger cross-lagged parameters between NA and subsequent rumination in RFDs (HINT on φNA→Rum; B = 0.253, SD = 0.12, 95% CI = [0.02, 0.49]). Detailed full model results for HINT are provided in supplementary materials E. This relationship is depicted in Figure 3 which shows that when associated with greater trait habitual characteristics, a momentary increase in NA evoked heightened rumination on the next measurement occasion.

[Figure 3 about here. In colour]

Additional analyses were carried out to test the robustness of this findings. When controlling for RRS-brooding, entered simultaneously with HINT on the between-level, HINT still remained a significant predictor of cross-lagged path between NA and subsequent rumination (HINT on φNA→Rum; B = 0.282, SD = 0.12, 95% CI = [0.04, 0.51]) whereas RRS-brooding did not demonstrate a significant effect (RRS-brooding on φNA→Rum; B = -0.15, SD = 0.12, 95% CI = [-0.39, 0.09]). RRS-brooding, when entered as the only predictor in the model, was a significant predictor

of average momentary levels of rumination (RSS-brooding on μRum; B = 0.184, SD = 0.07, 95% CI = [0.04, 0.32]), however, it did not significantly predict the cross-lagged path between NA and subsequent rumination (RSS-brooding on φNA→Rum; B = -0.09, SD = 0.12, 95% CI = [-0.34, 0.15]). Furthermore, when entering depressive symptoms simultaneously with HINT on the between-level, HINT still emerged as a significant predictor of greater mood-reactive rumination (HINT on φNA→Rum; B = 0.260, SD = 0.12, 95% CI = [0.17, 0.50]) whilst depressive symptoms did not (BDI-II on φNA→Rum; B = -0.01, SD = 0.12, 95% CI = [-0.23, 0.24]).

Exploratory Analyses: The Role of Depression Course and Early-Life Stress in Mood-Reactive Rumination in Daily Life of RFDs

We also explored if mood-reactive rumination in daily life of RFDs was associated with early-life stress and depression course. Results of the main analyses are presented in Figure 4. Detailed results are provided in supplementary materials F. As can be seen in Figure 4, depression course (number of depressive episodes, age of onset, stability of remission) did not emerge as significant predictors of mood-reactive rumination nor did habitual characteristics (HINT) moderate their effect to any significant degree.

[Figure 4 about here. In colour]

Self-reported severity of early-life stress did not emerge as a significant predictor of mood-reactive rumination. Cumulative early-life stress before the age of 17 (see Table 1) was, however, a significant predictor of larger cross-lagged associations between NA and subsequent rumination in RFDs (Cumulative stress on φNA→Rum; B = 0.270; see Figure 4). Additional analyses were carried out to assess if this finding was specific to the type of early-life stress in question. RFDs with a history of abuse (dummy coded as 1 or 0), demonstrated significantly greater mood-linked rumination compared to RFDs that did not report an early-life experience of abuse (Abuse on φNA→Rum; B = 0.261). Although cumulative early-life stress did not interact with self-reported habitual characteristics (HINT) in predicting mood-reactivity of daily ruminative thoughts (HINT x Cumulative stress on φNA→Rum; B = 0.01, SD = 0.13, 95% CI = [-1.5, 0.35]), a history of abuse did (HINT x Abuse on φNA→Rum; B = 0.332, SD = 0.15, 95% CI = [0.02, 0.60]). This relationship is depicted in Figure 5. Habitual characteristics of self-focused negative thinking (HINT) significantly predicted stronger temporal pairing between NA and subsequent rumination in participants reporting physical, sexual, or emotional abuse before age of 17, but not in RFDs reporting no such history of abuse.

[Figure 5 about here. In colour]

Discussion

Measures of the dynamic interplay between NA and rumination in daily life revealed significant mood-related reactivity of state ruminate thoughts in recurrent formerly depressed participants, but not healthy controls. To our knowledge, this is the first explicit test of the mood-reactivity of depressive rumination using mobile EMA assessment in a clinical sample. These findings extend previous results (Blanke et al., 2021; Hjartarson et al., 2021; Hoorelbeke et al., 2016; Moberly & Watkins, 2008) by showing that fluctuations in everyday NA may act as a trigger of subsequent ruminative thinking in euthymic individuals at high risk of experiencing depressive episodes. This is in line with recent theoretical accounts that define depressive rumination as a stable and enduring cognitive process that has become conditioned on negative mood (Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019). Importantly, these findings held when controlling for current depressive symptoms, in line with theoretical accounts of mood-reactive ruminative thinking as a potential vulnerability or risk marker (Watkins & Nolen-Hoeksema, 2014) and not just a concomitant of current depressive states (e.g., Ingram et al., 2011).

Like previous studies we identified a reciprocal relationship between NA and rumination, with rumination predicting subsequent changes in NA, and NA predicting changes in rumination to the same effect. However, the current findings suggest that mood-reactive rumination might be limited to individuals at-risk for depression. This does not necessarily contradict previous findings. Indeed, the few existent studies (Blanke et al., 2020, Hjartarson et al., 2020, Moberly & Watkins, 2008) were limited to student samples including individuals with a wide range of depressive symptoms and recruited both those who were and were not prone to

depression. Furthermore, the mood-reactivity of rumination was found to be moderated (Moberly & Watkins, 2008) and fully accounted for by current depressive symptomatology (Hjartarson et al., 2020). In line with this, the healthy control group utilized in the current study, which did not have any diagnosable history of depression or other mental disorders, did not demonstrate such mood-reactivity of rumination in daily life. Together these findings suggest that mood-reactive rumination varies according to the depression-risk spectrum in line with theoretical accounts of depressive rumination (Shaw et al., 2019; Watkins & Nolen-Hoeksema, 2014; Watkins & Roberts, 2020) and highlights the need to take differing levels of depression risk into account in future studies on mood-reactive rumination.

We also found that increased micro-level shifts in mood-dependent ruminative thinking were associated with the perceptions of one's negative self-focused thoughts being automatically triggered without intention and control. This replicates previous findings of Hjartarson et al. (2021) and is consistent with recent conceptualisations of depressive rumination as a response triggered by context (i.e., downward shifts in mood) rather than goals or intentions (Farb et al, 2015; Nolen-Hoeksema & Watkins, 2014; Shaw et al., 2019; Watkins & Roberts, 2020). Since mood-reactive rumination was only evident in at-risk individuals, and habitual characteristics specifically predicted the strength of the reactivity, this suggests that depression risk may be in the form of rumination being triggered with a high degree of automaticity in response to daily fluctuations in negative affect, making it difficult to control.

The emphasis that habitual accounts place on the automaticity of ruminative thinking is novel given that traditional instruments that assess rumination only measure the frequency of ruminative thinking in response to negative mood (Treynor

et al., 2003; Watkins & Roberts, 2020). HINT (but not brooding) was a significant predictor of the temporal pairing of NA and subsequent rumination whereas it did not predict the dynamic pairing between rumination and subsequent NA. Thus, the impact of rumination on affect was not associated with habitual characteristics, further highlighting the specificity of the current findings. Importantly, HINT remained a unique predictor of mood-reactive rumination when controlling for trait levels of brooding and current depressive symptoms. This suggests that HINT assesses aspects of mood-reactive rumination not fully captured by traditional trait measures of rumination and which cannot be explained by confounds with current depression status or overlap in negative content of the self-report measures. Thus, we may need to go beyond frequency to tap depression risk and concentrate on reactivity and automaticity, in addition to trait or mean levels of rumination.

Depression course (number of episodes, age of onset, and stability of remission) was not associated with mood-reactive rumination in daily life. This could reflect the homogeneity of the current clinical sample, consisting of high-risk individuals with at least three-lifetime depressive episodes, excluding the lower end of vulnerability and potentially inhibiting the ability to detect these effects (cf. Buckman et al., 2018), but may also indicate a mechanism independent of the depression course that constitutes a risk or vulnerability on its own (Shaw et al., 2019). Consistent with this view, we found that RFDs with a history of physical, sexual, or emotional abuse before the age of 17, demonstrated greater levels of mood-reactive rumination. Furthermore, habitual characteristics (HINT) predicted stronger mood-reactive rumination in RFDs reporting physical, sexual, or emotional abuse but not in RFDs without such a history. Prior findings show that rumination is associated with a

history of early-life stress and abuse (LeMoult et al., 2019) and recent habitual accounts of rumination suggest that stressful and abusive environments may constrain peoples' emotional coping repertoire, consolidating rumination as a mental habit when paired with negative mood over time (Shaw et al., 2019; Watkins & Roberts, 2020). Evidence suggests that stressful early-life events play a role in internalizing psychopathology through sensitization processes (McLaughlin et al., 2019) and reduced cognitive control (Jenness et al., 2020) that may pave the way for habit formation (e.g., Gordon et al., 2020).

Our results should also be interpreted in light of some limitations. Although the intensive longitudinal EMA methodology of the current study provided an inference of temporal causality, effects were generally small to moderate in size. Other contributing factors might also cause NA to evoke a subsequent ruminative response. Furthermore, although the current investigation identified the automaticity of mood-reactive rumination at the level of short-term dynamics as a potential risk factor, it remains to be tested whether it *predicts* depression onset and relapse using prospective designs and *under what conditions* it results in such emotional cascades (e.g., at times of heightened and persistent NA). Also, formerly depressed participants were required to have at least three previous episodes, in line with criteria used in studies of MBCT in recurrent depression (e.g., Williams et al., 2014). Although supporting our aim to study mood-reactive rumination in a group at high-risk of depression, this requirement precludes conclusions being drawn regarding people with fewer episodes. Although formerly depressed participants were in a euthymic state, as defined by not meeting diagnostic criteria for major depressive episode and having scores below established cut-off on measure of depressive

symptoms, they had elevated mean levels of daily negative affect during the EMA. However, controlling for depressive symptoms did not change the pattern in the findings, providing reassurance that our results are not confounded with current depressive states during the assessment period.

There exist yet no reliable behavioural proxies to measure rumination as-a-habit. In the current study, habitual characteristics were inferred from self-report. This highlights the need for the development of more specific behavioural measures of habitual rumination to clarify the unique role of habit in depressive rumination, while the research base of existing measures is expanded and their link with related constructs explored (e.g., metacognitive beliefs). Similarly, even though mood-reactive rumination was associated with a history of early-life stress, the study does not address how rumination develops as-a-habit in the first place. Other potential catalysts for rumination to consolidate as a mood-reactive habit have been suggested, such as cognitive inflexibility (Watkins & Nolen-Hoeksema, 2014), difficulties with attentional disengagement (Koster et al, 2011), and an imbalance in habit vs goal-directed behaviour control (Ólafsson et al., 2020). Future research should strive to assess if the strength of the habitual association between NA and rumination changes longitudinally as a function of these potential moderators. The EMA assessment methodology utilized in the current study is ideally suited to test these novel predictions.

The findings of the study could have significant clinical implications. They provide a direct test of the habitual model of rumination that has not been tested empirically so far and reveal a potential vulnerability marker that could constitute an important mechanism of change during therapy. Rumination that is triggered with a

high degree of automaticity might make it difficult for some people to fully recover from depression. Elevated rumination has been found to predict poorer outcomes following standard cognitive-behavioural therapy (Kertz et al., 2015). Preventive and acute therapy of depression may need to target the *context-response association* between negative mood and rumination and not just the *content* of the ruminative thoughts. This is in line with the recent development of interventions specifically designed to target the habitual qualities of rumination, such as rumination-focused CBT (Watkins, 2018) and mindfulness-based cognitive therapy (MBCT; Segal et al., 2018) where the ruminative response is specifically replaced with more helpful ways of responding (e.g., concrete thinking, compassion, mindfulness). Although rumination-focused interventions have found outcome effects that compare favourable to standard CBT (Hvenegaard et al., 2020; Teismann et al., 2014; Watkins et al., 2011) it remains to be seen whether they lead to greater reductions in rumination compared to other established treatments (Spinhoven et al., 2018).

The EMA measurement strategy used in the current study is also ideally suited to test whether interventions are successful in reducing the mood-reactive automaticity of ruminative thinking and to study mechanisms of change during therapy. Furthermore, the current findings suggest that rumination-focused interventions may be highly prescriptive for those with a history of childhood abuse. This is consistent with previous findings that MBCT provides additional protection over treatment-as-usual or placebo but only for those with a history of childhood abuse or adversity (Williams et al., 2014).

To sum up, the present results indicate that mood-reactive rumination may be a potential vulnerability marker for depression with rumination being habitually

triggered in response to momentary fluctuations in negative mood with a high degree of automaticity. Habitual rumination may constitute a risk independent of the depressive course and originate in early-life stress and abuse. Our findings suggest ways how depression vulnerability may emerge as a dynamic relationship between NA and rumination across time, not captured by traditional trait measures of rumination frequency. Future studies could expand on these findings by exploring whether targeting the mood-reactive automaticity of rumination as a mechanism of change during therapy can inform more personalized treatment selection and thereby reducing suffering and burden of depression.

Declaration of competing interest

The authors declare no conflicts of interest.

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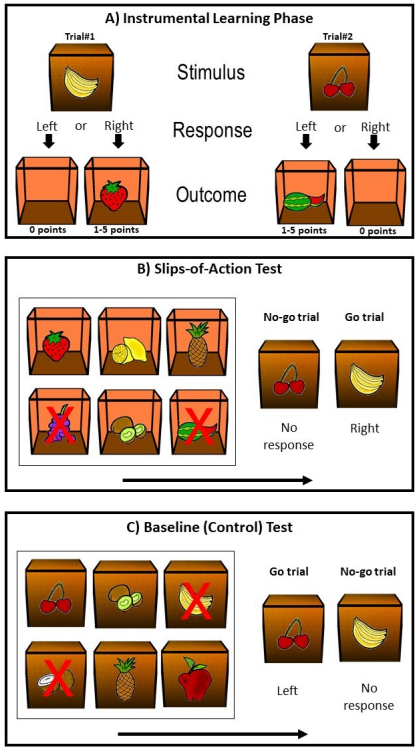
Appendix – The Fabuluous Fruit Game



The Fabulous Fruit Game. **A)** Instrumental learning phase. Two example trials are shown. On each trial, participants were presented with a closed box with a fruit image on the front (i.e., banana or cherry). Participants could open each box with either left or right button-press. If the correct response was selected (e.g., the right button-press for the banana box), another fruit reward was shown inside the box. If the incorrect response was selected, an empty box was shown. Participants could earn 1-5 points for each correct response (depending on how fast the response was made) and 0 points for incorrect response. **B)** The slips-of-action test. In this example, participants were presented with a display of six boxes with fruits inside. Two of the fruits were marked with red cross which meant they were devalued, and that participants would lose points if they opened boxes that included these fruits. Following the display, each box was presented in rapid succession (2 second per trail). Participants were instructed to withhold responses to boxes with devalued fruits ("no-go" trials) but respond to other boxes ("go" trials). In this example, the box with cherry on the front represents a "no-go" trial (as it contains the devalued melon inside) and the box with banana on the front represents a "go" trial (as it contains the still-valuable strawberry inside). **C)** The baseline control test. In this example, the display shows six closed boxes with fruit stimuli on the front. Again, two boxes are marked with red crosses which means they are devalued. Following the display, each box was presented in rapid (2 second) succession. Participants were instructed to withhold responses to boxes with devalued fruits on front ("no-go" trial) but respond to other boxes ("go" trials).