Habit degradation of health-risk behaviours in daily life

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M. Sc. Robert Edgren

from Finland

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Supervised by

Prof. Dr. Jennifer Inauen & Prof. Dr. Claudio Nigg

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"Habit is one of those words

psychologists so often use

without seriously questioning their meaning"

James E. Maddux (1997, p. 332)

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Abstract

Habit is the cognitively represented cue-behaviour association acquired through repeatedly performing a behaviour in response to a cue. Once a habit has been formed, it can be an impactful determinant of behaviour that is characterised by automaticity. In daily life, individuals may form habits that later conflict with their goals. Such unwanted habits may hamper efforts to change behaviour in the long term, calling for a need to understand how habits can be degraded. Although 4 theory-based strategies for habit degradation are recognized, little is known about how habit degradation unfolds over time or what factors determine change in habit strength. Accordingly, the empirical work of this dissertation aimed to describe how habit degradation occurs over time, identify its determinants, and understand how a habit degradation attempt can be supported. These aims were addressed in the context of health-risk behaviours that are known to be potentially influenced by underlying habits and that may have a substantial negative impact on health.

Methods: Two intensive longitudinal studies were conducted to examine habit degradation in daily life, each using daily self-report measures over 91 consecutive days. In both studies habit strength was measured with the Self-Report Behavioural Automaticity Index (SRBAI), and habit degradation strategy use operationalised with implementation intentions. Study 1 (N = 194; 11'805 SRBAI observations) employed 4 parallel non-randomised groups to investigate habit degradation across sedentary behaviour, unhealthy snacking, alcohol consumption and tobacco smoking. Study 2 (N = 313; 13'922 SRBAI observations) was a randomised controlled study using a 3x2 factorial design with an additional control group investigating unhealthy snacking related habit degradation. Multiple analytic approaches were used to investigate change processes including extensive person-specific modelling of habit strength time series, multilevel modelling, and the extraction of change indicators from person-specific time series for group-level comparisons. Non-linear change in habit strength over time was modelled with polynomial and asymptotic functions, as well as generalized additive models.

Results: The findings of the 2 studies are presented across 3 manuscripts. Manuscript I (based on Study 1) showed that habit degradation typically follows a decelerating negative trend over time, with large interindividual differences but no differences in the change process across the 4 behaviours. Manuscript II (also based on Study 1) found that habit strength was lower on days when individuals avoided performing the habitual behaviour after encountering the cue and experienced this as more rewarding than on average. Findings did not indicate differences between the habit degradation strategies of substitution, inhibition, and cue discontinuity. Manuscript III (based on Study 2) showed that habit degradation may initially occur at a faster rate when using a habit degradation strategy compared to control, but no other differences were observed across the various indicators of change investigated. This included null findings for experimentally manipulated reward and for comparisons between the habit degradation strategies of substitution, inhibition and reduced accessibility.

Discussion: Habit degradation was often a non-linear and decelerating process that varied considerably between individuals, with stabilization at a lower bound observed in a minority of trajectories. Refraining from performing the habitual behaviour in response to cue encounters appeared central to habit degradation. Additionally, findings suggest that intrinsic facets of reward may be influential in facilitating habit degradation. All 4 strategies were

capable of degrading habit, although substitution emerged as the preferred choice. However, findings also indicate that multiple strategies are often used collaboratively in daily life. Implementation intentions proved to be a viable approach for supporting habit degradation in daily life, which can be effectively facilitated remotely among motivated adults. While forming an implementation intention may enhance an immediate sense of goal-directed control, the provision of information about habit and the heightened self-monitoring inherent to intensive longitudinal studies may have also contributed towards habit degradation. Moving forward, habit research is encouraged to continue to develop methods for habit strength measurement in daily life, opportunities for which are discussed. Future research aiming to intervene on existing health-risk behaviour related habits may benefit from approaches that account for momentary goal-directed control and are sensitive to the potentially multifaceted nature of reward.

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List of abbreviations

AC:	Alcohol consumption
ANCOVA:	Analysis of covariance
ANOVA:	Analysis of variance
BIC:	Bayesian information criterion
BMI:	Body mass index
CI_{95}:	95% confidence interval
GAM:	Generalized additive model
ges:	Generalized eta squared
GPS:	Global positioning system
HS:	Habit strength
ICC:	Intraclass correlation coefficient
II:	Implementation intention
IQR:	Interquartile range
OB:	Other behaviours
OR:	Odds ratio
RFID:	Radio frequency identification
RMSE:	Root-mean-square-error
SB:	Sedentary behaviour
SD:	Standard deviation
SESOI:	Smallest effect size of interest
SRBAI:	Self-Report Behavioural Automaticity Index
SRHI:	Self-Report Habit Index
SRS:	Self-Regulation Scale
TS:	Tobacco smoking
TSRQ:	Treatment Self-Regulation Questionnaire
US:	Unhealthy snacking

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1. General introduction

"Every time just like the last, on her ship tied to the mast" (The Stranglers, 1981) are telling lyrics about addiction that capture a sense of lack of control. They also eloquently reflect the conventional wisdom surrounding a range of so-called 'bad habits' that individuals may experience in everyday life. For instance, the struggle to kick a smoking habit or resist an afternoon treat are all too common narratives. Unfortunately, such narratives often involve behaviours such as unhealthy eating and smoking – activities linked to elevated risks of non-communicable disease that could be prevented through behaviour change (Habib & Saha, 2010; Keeney, 2008; Muller et al., 2016).

Indeed, research shows habit is a relevant construct in relation to health-related behaviours. Alcohol consumption (Albery et al., 2015), tobacco smoking (Motschman & Tiffany, 2016), unhealthy snacking (Verhoeven et al., 2012) and sedentary behaviour (Conroy et al., 2013) can all be influenced by habits. But are habits truly as hard to overcome as conventional wisdom suggests? As will be demonstrated, there is in fact very little empirical evidence concerning habit degradation overall. This marks a substantial research gap that is deserving of more attention. Crucially, an evidenced based understanding of health-risk behaviour related habits' susceptibility to change, and conditions that influence this susceptibility to change, may serve to help develop interventions and empower individuals to improve their own well-being. While the practical relevance of investigating the malleability of unwanted habits is quite apparent, it is necessary to start this work by defining central terminology before proceeding further into the topic.

1.1 Habit terminology

In psychology habit is understood as a determinant of behaviour (Gardner, 2015; Gardner et al., 2016) and defined by a cognitively represented cue-behaviour association that is learnt through the repeated pairing of the cue and behaviour (Fleetwood, 2021). For example, after months of repeatedly smoking a cigarette while waiting for the bus for their commute to work, an individual may develop a habit for smoking (behaviour) when standing at the bus stop (cue).

As a determinant of behaviour, habit is distinguished by *automaticity* which encompasses cue-contingency, goal independence, unconsciousness, efficiency, and speed (Mazar & Wood, 2018; Moors & De Houwer, 2006). Returning to the earlier example, once the "smoking at the bus stop" habit has formed, encountering the cue (bus stop) is sufficient for subsequent smoking to occur; at which point smoking may be initiated quickly without using mental resources, and even despite having contradicting intentions to do so.

Behaviour that occurs as a consequence of habit is *habitual behaviour* (Gardner, 2015). This is an important distinction, as habit should not be considered both a behaviour and a determinant of behaviour (Fleetwood, 2021; Gardner, 2015; Maddux, 1997; Verplanken, 2006). However, habit is nonetheless often defined as a behaviour in research (Fleetwood, 2021) as is similarly the case in everyday language (Gardner, 2015), which highlights the need to clarify terminology used in this field.

As noted, habit is a cue-behaviour association while habitual behaviour is the behaviour performed as a consequence of that association. When a cue is encountered, the habit association is activated, which generates an impulse towards performing the habitual behaviour, though enactment is not necessitated (Gardner et al., 2024). Further distinctions are drawn between behaviour that is *habitually instigated* and / or behaviour that is *habitually executed* (i.e. the progression through the sub actions of the behaviour is performed habitually) (Gardner et al., 2016). This differentiation is relevant for understanding how habit may differently influence simple (e.g. one-step behaviours such as snacking) and complex behaviours (e.g. multistep behaviours such as going to the gym) (Gardner & Lally, 2018; Mullan & Novoradovskaya, 2018).

A related concept central to habit is *reward*. In this dissertation reward is defined as a desirable outcome anticipated or experienced by an individual as a consequence of performing a behaviour (Shiota et al., 2021). In addition, because cues are fundamental to habit, it is important to define them precisely. The cue integral to a habit is the situational context in which the behaviour has been repeatedly performed. Cues may include the physical environment or parts thereof, other persons, preceding actions (W. Wood & Rünger, 2016), time of day (Keller et al., 2021) or emotions (Pierce & Péron, 2022).

Several terms describe changes in habit strength, and their specific use in this dissertation is clarified here. The repeated performance of a behaviour in response to a cue, which strengthens the underlying cue–behaviour association, is referred to as *habit formation* (Lally et al., 2010). The intentional effort to weaken a previously established habit is termed *habit degradation*. This term encompasses both partial weakening and complete elimination of a habit. In contrast, *habit disruption* is reserved specifically for the complete undoing of a habit. Finally, *habit decay* refers to the natural weakening of habit due to non-performance of the habitual behaviour (Tobias, 2009).

Taken together, these definitions highlight that changing behaviour governed, at least in part, by habit may require targeting the underlying habit(s) (Gardner et al., 2021). In a similar vein, supporting the formation of beneficial habits can promote long-term positive behaviour change (Lally & Gardner, 2013). As such, there is value in studying habit, and accordingly approaches to this line of research are outlined next.

1.2 Paradigms to study habit

This section outlines two broad approaches to studying habit: laboratory-based and daily life studies. Both offer complementary strengths that have advanced our understanding of habit from unique perspectives. Presenting these complementary approaches serves to highlight the strengths and limitations of both approaches and, in doing so, justify the design of the empirical research in this dissertation.

Laboratory based studies investigating habit use paradigms with a high level of experimental control. In the case of investigating habit formation, this typically entails using some variant of the outcome devaluation (or contingency degradation) paradigms, where the reward value of a behaviour is decreased after training and the subsequent (dis)continuation of the behaviour following this devaluation is used to infer whether the behaviour is being performed habitually

or not (Dickinson et al., 1985; Thrailkill et al., 2025; Watson et al., 2022). The logic behind making this inference is that if a behaviour is goal-driven, the behaviour will no longer be performed after devaluation, whereas if a behaviour is habit-driven performance will continue despite devaluation (Watson et al., 2022). The strength of such experimental paradigms lies in the ability to make specific manipulations in a controlled environment, which for instance enables testing the role of cue-behaviour repetition as a mechanism of habit formation (Thrailkill et al., 2025). However, as in such paradigms habit is inferred through a binary classification of behaviour (i.e. performed or not performed), evidence of habit is indirect and overlooks the potential of behaviour being the result of a more complex interplay between goal- and habit-driven processes (Balleine & Dezfouli, 2019; De Houwer, 2019; Watson et al., 2022). Nonetheless, devaluation paradigms have also been combined with neuroimaging to give a more nuanced understanding of the neural correlates of habit (e.g. Guida et al., 2022; Luque et al., 2017). Alternative behaviour-based measurements of habit strength in laboratory settings use reaction times to infer habit strength. This includes implicit association tests (e.g. Hargadon, 2023) and lexical decision tasks (e.g. Neal et al., 2012). Ultimately however, habit inferred from highly controlled experimental paradigms may lack ecological validity in understanding habit as it naturally occurs in real life. Thus, research paradigms that study habit in daily life offer relevant complementary insights, as introduced next.

Daily life studies investigating habit, as considered in this dissertation, refers to tracking real-world habits longitudinally. To date the best available solution to measuring habit in daily life is through the self-reported perception of a specific cue-behaviour association (Gardner et al., 2022, 2025). The value of this approach to studying habit lies in capturing the lived experience associated with habit and consequently may inform how long it takes to form a habit (Lally et al., 2010) and what kind of cues can facilitate habit formation (Keller et al., 2021) in real life. Importantly, tracking real-world habits enables studying habit in realistic conditions characterised by an interplay between goal-driven and habit-driven processes (Saunders et al., 2025; Saunders & More, 2025). Moreover when investigating habit with intensive longitudinal data, that being data collected repeatedly from the same individuals with a high sampling frequency (e.g. daily) in their natural environment, recall bias is minimised and temporal dynamics can be investigated (Hamaker & Wichers, 2017; Trull & Ebner-Priemer, 2014). In this context, habit is currently predominantly measured using the Self-Report Behavioural Automaticity Index (SRBAI) (Gardner et al., 2012) which is a 4 item subscale derived from the Self-Report Habit Index (SRHI) (Verplanken & Orbell, 2003). While the self-report measurement habit, a construct that resides outside of conscious awareness, has been criticized (Hagger et al., 2015; Sniehotta & Presseau, 2012), it is also reasonable to claim an individual can reflect on a habit (Orbell & Verplanken, 2015) and to date this remains the best available option to track real-world habits (Gardner et al., 2025).

Taken together, both laboratory based and daily life paradigms to studying habit provide valuable insight into understanding habit. Simultaneously neither approach is able to measure habit comprehensively as it is expressed in an actor's mind. For the purpose of this dissertation, with health-risk behaviour related habits as the primary focus, it is especially crucial to study habit in the context of daily life—where real habits develop, and where the complexities of decision-making unfold under the influence of habit. At the same time, the experimental control

offered by laboratory paradigms provides unique opportunities to investigate mechanisms of change in real-life habits. The sections that follow build upon this premise: first by reviewing what is known about habit formation in daily life, and then by turning to habit degradation research, which will collectively further justify the aims and methods of the empirical studies presented in this dissertation.

1.3 Habit formation in daily life

As most habit research has focused on habit formation (Gardner et al., 2023), this is an appropriate starting point before turning to the less mature field of habit degradation. Examining the literature on habit formation also offers insight into constructs that may be relevant for understanding habit degradation. Accordingly the following section will outline the temporal process of habit formation, mechanisms and determinants of habit formation, and describe how implementation intentions (Gollwitzer, 1993) can be used to facilitate habit formation in daily life.

1.3.1 Temporal dynamics of habit formation

In daily life studies of habit formation, where participants have been instructed to perform a cue–behaviour repetition once per day, trajectories of increasing habit strength have been found to vary considerably across individuals; and estimates for the 'completion' of the habit formation process—defined as the time required for habit strength to reach a stable state—range from just a few days to almost a year (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010). Daily life studies on habit formation have consistently shown that habit strength tends to increase over time in a non-linear fashion, where this change process has varyingly been modelled using asymptotic functions (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010), the polynomial quadratic function (Keller et al., 2021) and most recently using generalized additive models (Baretta et al., 2024). Across these studies, the daily assessments of habit strength over a period of several months has enabled the investigation of how habit strength changes over time with high temporal resolution. Importantly, in this context modelling habit strength time series has shown that an increase in habit strength may be followed by stabilization and, as pioneered by Phillippa Lally and colleagues (2010), this process (along with the time needed for stabilization to occur) can be captured with non-linear functions that include an asymptote. Simultaneously however, this line of research has shown varying degrees of success in modelling habit strength time series, where asymptotic functions may not always be adequate in describing the data (Keller et al., 2021; Lally et al., 2010).

1.3.2 Mechanisms and determinants of habit formation

Habit formation has been proposed to follow a 4-step process: (1) forming an intention to perform a behaviour, (2) performing the behaviour in a goal directed manner and (3) consistently repeating the behaviour at cue encounter, which gradually (4) strengthens the corresponding cue-behaviour association (Gardner & Lally, 2018). In line with the definition of habit provided previously, the central mechanism of habit formation in daily life is cue-behaviour repetition (Gardner & Lally, 2018). Empirical evidence supports this, with findings

showing that higher rates in cue-behaviour repetition is associated to higher self-reported habit strength (Di Maio et al., 2022; Keller et al., 2021; Kilb & Labudek, 2022).

Beyond cue-behaviour repetition, research indicates that a range of additional factors influence the process of habit formation in daily life. Collectively these factors have been referred to as *determinants of habit formation,* and categorized as person-, cue-, and behaviour-related factors (Gardner & Lally, 2018). Person related factors stem from the individual, such as building an intention towards performing a health-promoting behaviour (Gardner & Lally, 2018). Cue related factors are influences attributable to the cue such as context stability (Gardner & Lally, 2018; Pimm et al., 2016). Lastly behaviour related factors are influences that are related to the behaviour such as the reward associated with performing the behaviour (Di Maio et al., 2022; Gardner & Lally, 2018; Kilb & Labudek, 2022). It is worth noting that while in the present dissertation reward is conceptualized as a determinant of habit formation in daily life, some authors go further to suggest reward is integral to defining habit in daily life (e.g. Phillips & Mullan, 2023), as is the case for habit research grounded in laboratory based studies (e.g. Burton & Balleine, 2022), where reward is an integral part of study paradigms. While the exact role of reward in habit formation remains somewhat unclear, which may in part depend on the context where habit is being investigated, what remains uncontested is that reward is of high relevance in habit formation.

1.3.3 Facilitating habit formation with implementation intentions

Repeatedly performing a behaviour in response to a cue encounter in order to facilitate habit formation may, understandably, require planning (Gardner & Lally, 2018). While planning was initially conceptualized as a cue-related factor by Gardner and Lally (2018), in the present dissertation planning is considered to have an overarching role relating to both the cue and behaviour. Categorisations aside, implementation intentions are recognized as a suitable way to operationalize planning for habit formation (Gardner & Lally, 2018; Lally & Gardner, 2013). This has been demonstrated, for example, in research on habit formation in the workplace (Trenz & Keith, 2024). An implementation intention is a specific type of plan that combines an intention with a commitment as to when, where and how this will be put into action (Gollwitzer, 1993). This is often pursued by formulating a plan that combines the opportunity to act (if-component) with the desired action (then-component) (Prestwich et al., 2015), for example "*If I am getting lunch at the cafeteria, then I will fill half my plate with salad*. Importantly, creating an implementation intention gives a plan attributes similar to a habit in that an association is forged between the cue and behaviour (Gollwitzer, 1993).

1.4 Habit degradation

The following section will start by outlining the current state of research on the temporal dynamics of habit degradation. Subsequently, the theory and evidence base on habit degradation regarding mechanisms and determinants will be addressed. Finally, the section will conclude by considering what is known about facilitating habit degradation with implementation intentions.

1.4.1 Temporal dynamics of habit degradation

Very little evidence is available on how habit strength may decrease over time as an individual sets out to degrade a habit. Habit degradation studies that have typically investigated this phenomenon using study designs with pre-post measurements (Armitage, 2016; Hill et al., 2025), and in some instances also with follow-up measurements (Pedersen et al., 2018; Walker et al., 2015) of habit strength. To date, only one study has collected intensive longitudinal data on habit strength in the context of habit degradation (Di Maio et al., 2025), which dealt with habit substitution of commuting behaviours. This study found habit strength to decrease modestly at a linear rate over a 13 week period (Di Maio et al., 2025). However, even this study had lower frequency of data collection compared to intensive longitudinal studies on habit formation, as habit strength was assessed daily for 5 consecutive days at three week intervals (Di Maio et al., 2025), opposed to daily responding continuously over 12-15 weeks as seen in habit formation research (Baretta et al., 2024; Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010).

In sum, the temporal dynamics of habit degradation remain largely unexplored, particularly at high temporal resolution. Extending time series analysis of habit strength to habit degradation is thus timely. This would serve to strengthen our understanding of how habit changes over time and, in turn, help design timely habit degradation interventions. Importantly, accurate inferences from time-series data require modelling the process of change appropriately—a methodological challenge that remains, to date, largely unaddressed in the context of habit degradation.

1.4.1 Mechanisms and strategies of habit degradation

Theoretically, two mechanisms have been proposed for habit degradation. First, it is theorized that in the absence of cue-behaviour performance, habit strength will weaken over time (Tobias, 2009). Second, it is theorized that in order to degrade a habit, the existing habit must be replaced by a new habit (Gardner et al., 2021). Alongside these theoretical accounts, 4 alternative strategies to pursue habit degradation are recognized, each targeting a distinct part of the habit activation process (Gardner et al., 2024). These strategies will be described below with empirical examples, but it is useful to first note the theoretical implications for the proposed mechanisms of change. If habit degradation is assumed to occur through non-performance, then any strategy that successfully prevents cue–behaviour enactment can reduce habit strength. By contrast, if degradation is assumed to require replacement, then only strategies that lead to the formation of a new habit will be effective in weakening the old one.

The 4 recognized habit degradation strategies are cue discontinuity, substitution, inhibition and reduced accessibility (Gardner et al., 2024). **Cue discontinuity** refers to avoiding the focal cue, which in turn prevents the habit impulse from being activated (Gardner et al., 2021, 2024). Empirically, cue discontinuity has been demonstrated at the example of commuting habits after an office relocation (Walker et al., 2015). In this study, at 1 and 4 weeks after the relocation habit strength was shown to decrease compared to baseline, regardless of whether the mode of travel changed after the relocation (Walker et al., 2015). **Substitution** in turn refers to replacing the existing habit with a new habit by repeating a new behaviour when encountering the cue that is associated with the old habit (Gardner et al., 2021, 2024). Empirically substitution has

also been demonstrated at the example of commuting habits (Di Maio et al., 2025). Here as participants attempted to change their mode of transport to a more sustainable alternative, the habit strength for the new commuting behaviour was shown to increase while the habit strength for the old commuting behaviour decreased over a 14-week period (Di Maio et al., 2025). **Inhibition** refers to wilfully abstaining from performing the habitual behaviour after encountering the cue, for example with motivational self-talk (Gardner et al., 2021, 2024; Quinn et al., 2010). Inhibition has been demonstrated empirically at the example of electronic device use to procrastinate sleep (Hill et al., 2025). Here avoiding device use to procrastinate sleep was found to decrease habit strength after 3 weeks compared to baseline (Hill et al., 2025). Lastly, **reduced accessibility** refers to limiting the accessibility of performing the habitual behaviour when encountering the cue (Gardner et al., 2024). The principle of reduced accessibility has been showcased at the example of a smoking ban introduced to bars, which effectively limited the accessibility of smoking in this environment (Orbell & Verplanken, 2010). While this study showed that higher habit strength was associated with a higher likelihood for habitual behaviour slips following the smoking ban (Orbell & Verplanken, 2010), to the present author's knowledge, the effect of reduced accessibility on habit strength has not been investigated.

Taken together, the literature suggests that abstaining from cue-behaviour performance can degrade habit strength, consistent with Tobias's (2009) proposal. However, degrading a habit through replacement with a new one (i.e. substitution) arguably constitutes a more substantial intervention on habit compared to the other strategies. This aligns with the alternative theoretical account suggesting that only substitution can effectively degrade habit strength (Gardner et al., 2021, 2024). Thus, regardless of the mechanism to habit degradation, it is reasonable to assume substitution may be more effective than the alternative strategies. There is however very limited evidence of the relative effectiveness of the different habit degradation strategies. As such, it remains an open research question as to what the most effective strategy in habit degradation is. To the present author's knowledge, only 1 study has compared the effectiveness of multiple habit degradation strategies. Specifically, in the study by Hill and colleagues (2025), both inhibition and substitution were found to decrease habit strength for bedtime device use to procrastinate sleep to similar extents. However, as habit strength was only measured at two time points three weeks apart, interpretation warrants caution.

1.4.2 Determinants of habit degradation

As no theoretical framework currently exists for the determinants of habit degradation, the corresponding framework developed in the context of habit formation (Gardner & Lally, 2018) serves as an informative starting point. Accordingly, the evidence base on the determinants of habit degradation will subsequently be introduced in terms of person, cue and behaviour related factors. As will become apparent, because empirical research on habit degradation remains scarce, the evidence concerning determinants of habit degradation is correspondingly limited.

Regarding **person related factors**, to the present author's knowledge, there is no direct evidence of such determinants of habit degradation. However intriguing indirect evidence stems from experimental findings suggesting that the performance of habitual behaviour is more likely when goal-directed control is compromised, for instance due to stress (Fournier, d'Arripe-

Longueville, & Radel, 2017; Neal et al., 2013). Importantly, these findings suggest that person related factors linked to self-regulation and stress may play a role in determining the success of an attempt in habit degradation. It is thus reasonable to assume that person related factors may play a role in habit degradation, and this needs to be investigated empirically in daily life. Regarding **cue related factors** as determinants of habit degradation there is no evidence to the knowledge of the author, marking a substantial research gap. However, it is for example conceivable that a cue with high context stability (e.g. weekday mornings on the way to work) may enable acting according to plans to not act habitually upon encountering the cue more easily compared to a cue that is encountered sporadically (e.g. when stressed).

Regarding **behaviour related factors** of habit degradation, the existing literature has some direct evidence. First, regarding habit degradation in daily life there is evidence to suggest that higher than sample average (i.e. between person effect) repetition of new commuting behaviour is associated with lower habit strength for an old commuting behaviour, and that experiencing higher than person average (i.e. within person effect) regret for the old commuting behaviour is associated (albeit not statistically significant) with lower habit strength for the old commuting behaviour (Di Maio et al., 2025). Second, findings from laboratory experiments suggest that making a counter-habitual response more rewarding can strengthen goal directed control and thus facilitate avoiding habitual responding (Ceceli et al., 2020). Extending such approaches—where reward is experimentally manipulated—into daily life contexts would be highly valuable for clarifying the role of reward in real-world habit degradation. In summary, behaviour related factors seem relevant in habit degradation and should be investigated more thoroughly. To this end, comparing how degradation unfolds across different behaviours may also yield important insights into behaviour-related factors that facilitate or hinder the degradation of habits.

1.4.4 Facilitating habit degradation with implementation intentions

To investigate habit degradation in daily life, individuals need to be provided with some tools to successfully pursue this goal. Below the case will be made that implementation intentions are a suitable means to facilitate habit degradation.

Firstly, the study by Adriaanse and colleagues (2011) provided experimental evidence for the proof of principle that existing habits can be challenged with the help of implementation intentions. Specifically, based on response times on a lexical decision task it was shown that formulating an implementation intention can make a counter-habitual intention more accessible, facilitating goal-oriented control to not act habitually (Adriaanse et al., 2011). The power of implementation intentions in challenging existing habits has subsequently been extended to habits in daily life. Specifically, it has been shown that implementation intentions aimed at avoiding smoking in specific situations can decrease habit strength for smoking one month later (Armitage, 2016).

Previous studies have also shown that for behaviours potentially influenced by underlying habits, implementation intentions can facilitate a change in behaviour. Specifically this has been shown for unhealthy snacking (Tam et al., 2010), meat consumption (Rees et al., 2018), and recycling (Holland et al., 2006). While these latter studies show that implementation intentions can influence behaviour, rather than habit itself, these findings are nonetheless encouraging for the development of habit degradation interventions. Specifically, considering the alternative

mechanisms of change in habit degradation outlined previously, an implementation intention that leads to non-performance of the cued behaviour *or* that facilitates repetition of a new behaviour in response to the cue, should be able to facilitate habit degradation.

In summary, there is ample evidence that implementation intentions provide a suitable way to operationalise the pursuit of habit degradation. However, it remains largely unknown how the specific characteristics of implementation intentions may impact their effectiveness in degrading habits. Addressing this research gap is relevant, as such insights could inform the future development of interventions targeting habits. Relatedly, the characteristics of implementation intentions have been shown to influence their effectiveness on behaviour change in a meta-analysis (Sheeran et al., 2025). For example, these findings indicate that creating implementation intentions with a cue-contingent format have a larger effect compared to when a plan is made without the cue-contingent format (Sheeran et al., 2025). Furthermore, effect size may vary based on whether the intended response is, for example, behavioural approach, to direct attention, or to facilitate self-talk (Sheeran et al., 2025). Accordingly, studies aiming to degrade habits using implementation intentions should also examine how the characteristics of these plans shape their impact on habit degradation.

1.5 Aims and scope of dissertation

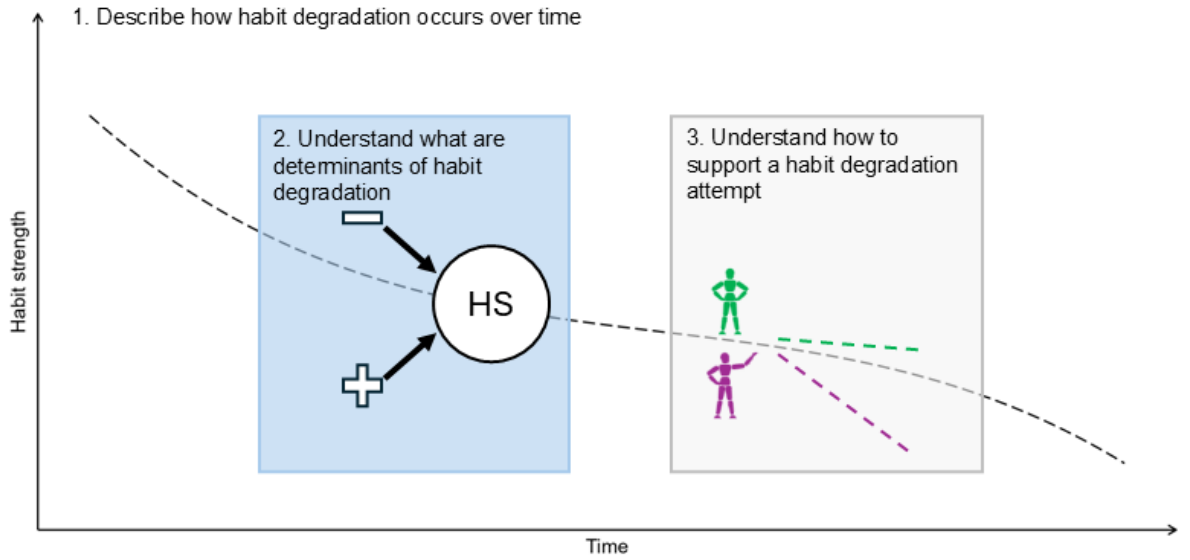
This dissertation aims to contribute to habit research by focusing on habit degradation of health-risk related behaviours in daily life. The overarching aims are subsequently specified, followed by a statement on the authors epistemological stance and an overview of the empirical work conducted. Chapters 2., 3., and 4. present the cumulative manuscripts that constitute the original empirical research of this dissertation.

1.5.1 Objectives and research questions

The objectives of this dissertation are to (1) describe how habit degradation occurs over time, (2) understand what are determinants of habit degradation, and (3) understand how to support a habit degradation attempt with theory-based strategies and implementation intentions (see Figure 1). These objectives are addressed in the context of daily life and health-risk behaviour related habit degradation. More specifically, the overarching research questions guiding the dissertation are:

1. *How does habit strength change over time during a habit degradation attempt, and how can this change be modelled?*
2. *What person, cue, and behaviour related factors are associated with habit degradation, and how does reward impact the habit degradation process?*
3. *Does the use of habit degradation strategies facilitate habit degradation, and do different strategies vary in their effectiveness?*

Figure 1. Conceptualisation of objectives to the dissertation.

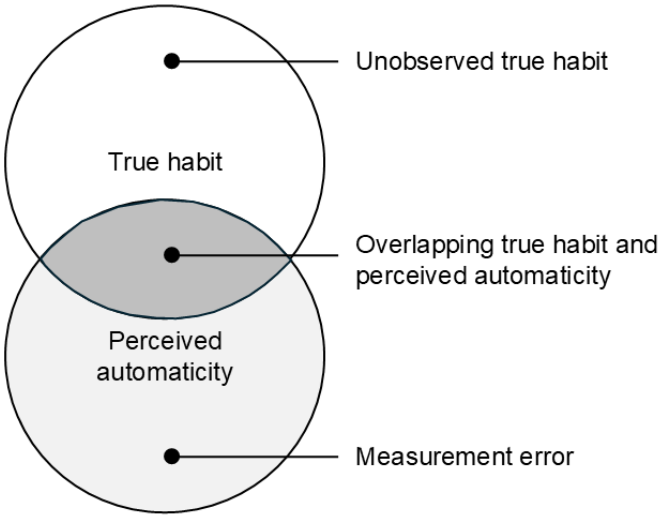


Note. HS: Habit strength. The minus sign with a downwards pointing arrow refers to factors that facilitate habit degradation. The plus sign with an upward pointing arrow refers to factors that impede habit degradation.

1.5.2 Assumptions of knowledge acquisition

As noted previously, habit strength measurement by self-report has been criticised (Hagger et al., 2015; Sniehotta & Presseau, 2012). For this reason, when conducting research in this context, it is important to address the underlying assumptions about knowledge acquisition. First, the author adopts post-positivistic ontological assumptions (Spencer et al., 2020). This position holds that there is an observable external reality—in this case, *true habit* (Rebar et al., 2018)—for which accurate representation cannot be achieved. Second, the author adopts phenomenological assumptions about epistemology (Spencer et al., 2020). This view holds that our knowledge and understanding about a true habit, and the strength of that habit, stems from our experiences. These experiences that inform our understanding of habit, in turn, may consists of an array of different experiences that vary in their relevance in understanding true habit. For example, the inferences an individual makes about the strength of a true habit they have acquired may draw on, among other things, memories of a history of repetition, and recent sensations and experiences related to cue encounters and subsequent behaviour (see Figure 2). This epistemological assumption aligns with the usage of the SRBAI, as this scale captures perceived automaticity (Hagger et al., 2015; Orbell & Verplanken, 2015). To summarise, the author maintains that, based on experiences informative of perceived automaticity, it is possible for an individual to make accurate inferences about the strength of an existing true habit.

Figure 2. Conceptualisation of habit measurement by self-report.



Note. True habit refers to the objective reality underlying habit. Perceived automaticity refers to observed habit strength based on responding to the Self-Report Behavioural Automaticity Index. The overlap between true habit and perceived automaticity is figurative, and thus the proportion of overlap in the figure should not be interpreted. This visualisation is inspired by the Venn diagram presented by Rebar et al. (2018).

1.5.3 Description of the empirical studies

The present dissertation consists of 2 empirical studies, the findings of which are presented across 3 manuscripts. Both studies are intensive longitudinal, where self-report data was collected daily for 91 consecutive days in end-of-day e-diary questionnaires from convenience samples of individuals interested in changing an existing habit. In both studies the first week (days 1-7) of participation was a cue identification phase, where participants observed their own behaviour to help identify a cue associated with the unwanted habitual behaviour. On day 7, participants selected 1 cue associated to the habitual behaviour, which served as the target of habit degradation. In both studies during the subsequent 12 weeks (days 8-91) participants actively tried to degrade the self-selected habit with the help of a self-defined implementation intention. In both studies habit strength was measured with the SRBAI. Beyond these commonalities the 2 studies differed as subsequently described.

Study 1 had 4 parallel non-randomised behavioural groups (sedentary behaviour, unhealthy snacking, tobacco smoking and alcohol consumption). Data collection was conducted with online questionnaires that were sent to participants via text message. On day 7 participants were introduced to 3 habit degradation strategies (inhibition, substitution and cue discontinuity) and instructed to formulate an implementation intention according to their preferred strategy. Halfway through the habit degradation phase (day 48), participants had the opportunity to update their implementation intention, nonetheless maintaining the same cue selected on day 7. The data collected (N = 194; 11’805 SRBAI observations) was first used to describe how habit strength changes over time as an individual sets out to degrade a habit using person-specific and multilevel modelling with 6 prespecified models of change, and explore whether and how the temporal trajectories differ between the 4 behaviour groups. These findings are presented

below in Manuscript I (chapter 2.) (Edgren et al., 2024). Noteworthily, in Manuscript I the term habit decay is used in place of habit degradation per the definitions provided in section 1.1, as the current stance on terminology was not yet established upon publication of this manuscript. Subsequently, the associations of person, cue, and behaviour related determinants, habit degradation strategies, and implementation intention characteristics with habit strength were explored. These findings are presented below in Manuscript II (chapter 3.) (Edgren & Inauen, 2025a).

Study 2 was a randomised controlled study using a 3x2 factorial design with an additional control group. The study focused on unhealthy snacking related habit degradation. Data collection and experimental manipulation was conducted with a smartphone app developed for the study. On day 7 participants were randomly assigned to one of three strategy groups (inhibition, substitution or reduced accessibility) and a reward condition (reward or no reward), or a control group. Participants were subsequently instructed to formulate an implementation intention according to their assigned strategy. Starting from day 8 participants tried to degrade their habit with the help of their implementation intention. During this time participants were instructed to record in the app when they encountered their cue and whether unhealthy snacks were subsequently consumed, which served as the trigger for in-app reward delivery for participants in the reward condition. The data collected ($N = 313$; 13'922 SRBAI observations) was used to test the effect of habit degradation strategy and reward based on 4 indicators of change extracted from person-specific habit strength time series. These findings are presented in Manuscript III (chapter 4.) (Edgren et al., 2025).

The Ethics Committee of the Faculty of Human Sciences at the University of Bern has granted ethical approval for the presented studies (Nr. 2021-11-00004).

The Swiss National Science Foundation has funded the presented studies (Grant Number: 10001C_200895).

2. Manuscript I – The temporal trajectories of habit decay in daily life: An intensive longitudinal study on four health-risk behaviours

This manuscript has been published: Edgren, R., Baretta, D., & Inauen, J. (2024). The temporal trajectories of habit decay in daily life: An intensive longitudinal study on four health-risk behaviours. Applied Psychology: Health and Well-Being, aphw.12612. https://doi.org/10.1111/aphw.12612

Supplementary material I contains additional information for this manuscript.

Author contributions

Robert Edgren: Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization, Project administration, Data curation. **Dario Baretta**: Methodology, Formal analysis, Visualization, Writing – review and editing. **Jennifer Inauen**: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – reviewing and editing.

Abstract

Habits are cue-behaviour associations learned through repetition that are assumed to be relatively stable. Thereby, unhealthy habits can pose a health risk due to facilitating relapse. In the absence of research on habit decay in daily life, we aimed to investigate how habit decreases over time when trying to degrade a habit and whether this differs by four health-risk behaviours (sedentary behaviour, unhealthy snacking, alcohol consumption, and smoking). This 91-day intensive longitudinal study included four parallel non-randomized groups (one per behaviour; N = 194). Habit strength was measured daily with the Self-Report Behavioural Automaticity Index (11,805 observations) and modelled over time with constant, linear, quadratic, cubic, asymptotic, and logistic models. Person-specific modelling revealed asymptotic and logistic models as the most common best-fitting models (54% of the sample). The time for habit decay to stabilize ranged from 1 to 65 days. Multilevel modelling indicated substantial between-person heterogeneity and suggested initial habit strength but not the decay process to vary by behavioural group. Findings suggest that habit decay when trying to degrade a habit typically follows a decelerating negative trend but that it is a highly idiosyncratic process. Recommendations include emphasizing the role of person-specific modelling and data visualization in habit research.

2.1 Introduction

Habits, centrally defined as cue–behaviour associations learned through repetition (Fleetwood, 2021; Gardner, 2015; Gardner et al., 2022), may have a substantial negative impact on health through sustaining health-risk behaviour. Smoking, alcohol consumption, lack of physical activity, and unhealthy diet are leading causes of premature deaths that are preventable through behavioural change (Habib & Saha, 2010; Keeney, 2008; Muller et al., 2016). These behaviours can be influenced by underlying habits (Albery et al., 2015; Conroy et al., 2013; Gardner et al., 2021; Ray et al., 2020; Webb et al., 2009), whereby encountering the cue automatically triggers an impulse towards habitual behaviour (Gardner, 2015). Previously formed habits can hinder achieving counter-habitual behavioural change, as evidenced for example by unintentional behavioural slips (Orbell & Verplanken, 2010). Thus, weakening (or "breaking") habits in addition to changing behaviour may be necessary. However, habit decay may be challenging due to the nature of habit, in particular its key feature, automaticity. Automaticity entails cue contingency, goal independence, functionality without conscious awareness, and processing characterized by efficiency and speed (Mazar & Wood, 2018; Moors & De Houwer, 2006). This may lead habitual responses to be favoured under conditions in which self-control is depleted, such as when stressed (Neal et al., 2013; W. Wood & Rünger, 2016). Furthermore, factors related to the behaviour itself may add complexity to the decay process. Particularly, the reward value of an unhealthy habitual behaviour may hamper efforts to abstain, especially if the alternative does not carry the same appeal (Gardner et al., 2021).

Pioneering research on habit decay suggests that an old commuting habit may gradually decrease as a new commuting habit gradually increases over 4 weeks after the relocation of the workplace office (Walker et al., 2015). Additionally, implementation intentions have been shown to decrease habit strength of smoking (Armitage, 2016) and to replace old waste disposal habits with recycling (Holland et al., 2006). Although these studies provide insights about the conditions that may facilitate habit decay, they do not inform about how habit decay may occur over time in daily life at a granular level.

2.1.1 Temporal trajectories of habit strength in daily life

In the absence of research on how habit decay occurs over time, findings from "habit formation tracking studies" (Gardner et al., 2022, p. 3) can roughly serve to inform how this process may occur and what methods are suitable for this field of research. To our knowledge, five studies have examined the temporal trajectory of habit formation with intensive longitudinal data over a period of several months (Baretta et al., 2024; Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010; Van Der Weiden et al., 2020). Across these studies, participants were instructed to establish a new habit by repeating a novel behaviour (predominantly nutrition- or physical activity-related) once per day in response to a specified cue for approximately 3 months, where habit strength was recurringly assessed with the Self-Report Habit Index (SRHI) (Verplanken & Orbell, 2003) or its subscale, the Self-Report Behavioural Automaticity Index (SRBAI) (Gardner et al., 2012). Findings coherently suggest that successful habit formation may be described by a non-linear increasing trend, where the rate of change gradually slows down as the habit strength approaches an upper bound (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010; Van Der Weiden et al., 2020). Furthermore, findings suggest that the change in habit strength over time

varies considerably between individuals, where consistent performance of the novel behaviour in response to encountering the cue is key for habit formation to occur (Baretta et al., 2024; Keller et al., 2021; Lally et al., 2010). Based on these studies, the time needed for habit formation to occur has been estimated to range from a matter of days to almost 1 year, with potentially only a minority of participants succeeding in forming a habit (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010). Noteworthily, estimates of long duration (e.g. 335 days) (Keller et al., 2021) are based on extrapolated predictions beyond the observed time frame.

In terms of modelling the process of change, important commonalities and differences across the studies can be identified. The change in habit strength has been modelled by participants' individual trajectories (Lally et al., 2010), by group-level modelling (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Van Der Weiden et al., 2020), or by combining both approaches (Baretta et al., 2024; Keller et al., 2021). Modelling person-specific trajectories has the advantage of highlighting the idiosyncratic nature of habit formation (Keller et al., 2021; Lally et al., 2010), but research questions related to group differences in habit change processes may be more appropriately addressed with group-level modelling (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021). The specific models used for describing change over time include non-linear models estimating an upper asymptote (i.e. an upper bound), including a power curve (Lally et al., 2010), an asymptotic model (Baretta et al., 2024; Keller et al., 2021), and a logistic model (Fournier, d'Arripe-Longueville, Rovere, et al., 2017), as well as the quadratic model (Keller et al., 2021; Van Der Weiden et al., 2020). Taken together, no single model seems suitable for predicting habit strength over time across all participants (Keller et al., 2021; Lally et al., 2010). While asymptotic models have the strength of including parameters with meaningful interpretation—particularly the upper asymptote allowing for estimation of time for habit formation to occur (Lally et al., 2010), the quadratic model is more flexible in modelling diverse arrays of habit strength trajectories, including discontinued habit formation (Keller et al., 2021). More recently, machine learning methods and objective behavioural data have been used to model habit formation over time based on context-related predictability (Buyalskaya et al., 2023). Concordant with self-report studies, these findings suggest habit strength to increase asymptotically, with large differences evident between individuals. To conclude, based on the described habit formation research, it is reasonable to assume that habit decay varies considerably between individuals, multiple models may be required to describe this change process across a sample, and that idiographic and nomothetic approaches may provide complementary insights.

2.1.2 The present study

This study seeks to extend research by investigating the trajectory of habit decay in daily life. We will do so at the example of four health-risk behaviours to explore whether the temporal trajectories are similar or distinct across behaviours. We chose the four key health-risk behaviours that contribute to non-communicable disease (Habib & Saha, 2010; Keeney, 2008; Muller et al., 2016) as examples, that is, sedentary behaviour, unhealthy snacking, alcohol consumption, and tobacco smoking. The first aim of the study was to describe how habit strength trajectories change in individuals who set out to degrade a habit. To this end, we fit six models (constant, linear, quadratic, cubic, asymptotic, and logistic) to investigate which models

display the best fit with person-specific and group-level models. Person-specific models were further used to estimate how long it takes for habit decay to stabilize. The second aim of the study was to examine, based on group-level modelling, whether habit decay trajectories differ between the four health-risk behaviours. The coregistration (Benning et al., 2019) of the study is available online (https://osf.io/g6wpr).

2.2 Methods

This study reports the primary findings from an online-based 91-day intensive longitudinal study with four parallel non-randomized groups, that is, one of four behaviours that participants self-selected to change: sedentary behaviour, unhealthy snacking, alcohol consumption, or tobacco smoking.

2.2.1 Population and sample

Eligibility criteria for participation were age of at least 18 years and willingness to reduce one of the four health-risk behaviours. Participants were excluded if they were not fluent in German, did not own an iOS or Android smartphone, or did not provide informed consent. Additionally, participants were required to respond to the Day 7 survey to proceed with study participation. Participants were retained for analyses if they provided at least six habit strength (SRBAI) measurements to ensure sufficient data (Keller et al., 2021) and engaged with the study at least until the midpoint of the habit decay phase (Day 48) to ensure sufficiently long duration of participation.

Due to a lack of reliable estimates of required parameters, a priori power analysis was not conducted. The planned sample size of 200 (n = 50 per behavioural group) was based on a rule of thumb for achieving power of .80 (alpha = .05) in a two-level model (observations nested within individuals) to detect a small effect size of time and a medium effect size for between person differences, assuming a large intraclass correlation coefficient (Arend & Schäfer, 2019).

2.2.2 Measures

The primary outcome of interest (habit strength) was measured with the 4-item SRBAI (Gardner et al., 2021) and adapted from the German translation (Verplanken, 2007). The SRBAI assesses the perception of habit-related automaticity (Gardner & Lally, 2023; Orbell & Verplanken, 2015). The SRBAI was phrased to reference performing the target behaviour in response to the cue selected by the participant (in brackets), such as "Smoking in this situation (drinking coffee in the morning) is something …" followed by four statements scored on a 5-point Likert scale, for example, "… that I do automatically." Items were scored from 0 to 4, with higher scores indicating stronger agreement. The overall SRBAI score was calculated by averaging the four items. Habit strength was measured daily starting from Day 7 (after participants had defined their cue) until study completion (Day 91). In the current dataset, the SRBAI displayed high reliability for between-person averages ($R_{kf} \approx 1$) and to detect within-person change ($R_c = 0.86$) (Cranford et al., 2006; Keller et al., 2021).

While studies have convincingly shown that individuals can reflect on their habits (Orbell & Verplanken, 2010), tracking change in habit based on the perception of habit strength (SRHI/SRBAI) has also received criticism. The case has been made that such self-report may mirror cue-behaviour performance (Sniehotta & Presseau, 2012), where for example the

perception of habit strength could decrease because of not experiencing the relevant cue (Keller et al., 2021). On the contrary, it is reasonable to assume that an individual with a strong habit can reflect on their perceived automaticity, and the noted validity concerns are inherent to all self-report measurements of mental processes (Orbell & Verplanken, 2015). In acknowledgement of this controversy, exploration of habit strength trajectories in relation to cue-behaviour performance was conducted with data visualization (see Supplementary material I section 6.2.5).

At baseline, several interindividual difference measures were assessed. The following constructs will be used as sample descriptors in this study and are not outcomes. Target behaviour performance prior to baseline was measured using frequency measures for each of the four health-risk behaviours. Time spent sedentary for the past week was measured with the International Physical Activity Questionnaire short format (Craig et al., 2003). Past unhealthy snacking, alcohol consumption, and tobacco smoking frequency were assessed by asking participants to report on how many days in a typical week these products are consumed and to estimate how many servings/units are consumed on such days. Intention (De Bruijn et al., 2012) to change the selected habitual behaviour was assessed on Day 7 with two items (scored 0–4) that were averaged. See Supplementary material I section 6.1.1 for further details on item content.

2.2.3 Procedure

Recruitment was primarily conducted with social media advertisements (one for each behaviour), noting habit decay as the focal point of the study. Data collection took place in Switzerland between September 2022 and April 2023. Study participation lasted for 91 days, during which participants received daily end-of-day e-diary questionnaires (via SMS including link to questionnaire). Upon beginning participation, participants were informed about the definition of habit and the procedural phases of the study. During the first 7 days, participants were instructed to observe and report cues experienced that trigger instigation of their target health risk behaviour. On Day 7, participants were instructed to select one cue in response to which they wanted to change their habitual response for the following 84 days. Subsequently, participants were introduced to the three alternative strategies for disrupting a habit (substitution, inhibition, and discontinuation; see Supplementary material I section 6.1.2 for instructions provided to participants). Substitution constitutes replacing an old habit by pairing a new behavioural response to the cue that generates the existing habitual response (Gardner et al., 2021; Gardner & Lally, 2018). Inhibition refers to the wilful inhibition of enacting the habitual behaviour after the habit impulse has been triggered (Gardner et al., 2021; Quinn et al., 2010). Discontinuation refers to the avoidance of encountering the cue that triggers an impulse towards the habitual behaviour, eliminating the possibility of the habit impulse from being activated (Gardner et al., 2021; Walker et al., 2015). Participants were instructed to choose one strategy and guided to formulate an implementation intention (Gollwitzer, 1993), also known as an if-then plan, according to the selected strategy. Specifically, participants were instructed to formulate a plan linking their selected cue (if-component) to a desired response (then-component); for example, “If I am watching TV in the evening, then I will eat grapes.” Of note, for the discontinuation strategy, the if-then plan instructions guided to avoid future cue encounters, for example: “If I arrive home tonight, then I will remove all snacks from my

home." On Day 48, participants had the opportunity to update the strategy and then-part of their implementation intention to support the continued viability of plans (this did not impact results, see analysis in the Supplementary material I section 6.2.4). At completion, participants were reimbursed (100 CHF for full study, or 7 CHF per week if participation was shorter).

2.2.4 Analysis and preprocessing

Data analyses were conducted with R Statistical Software version 4.1.2 (R Core Team, 2021). The online end-of-day e-diary questionnaire assessing habit strength was accessible throughout the study period. Responses given between times 0:00 a.m. and 12:00 p.m. were recoded to refer to the previous day. Duplicate e-diary responses for the same day were removed by averaging. No partial responses to the SRBAI scale were evident. SRBAI observations were missing for non-consecutive days and for longer sequences of days (henceforth referred to as missing gaps). Long missing gaps were more prominent in the second half of the time series. Non-consecutive missing observations were imputed (see Supplementary material I section 6.2.2), and long missing gaps retained as such. For details on divergence from protocol, see Supplementary material I section 6.1.6.

2.2.5 Person specific models

To examine how habit decay occurs at the person-specific level when trying to degrade a habit, habit strength (dependent variable) was modelled over time (independent variable) for each participant with six prespecified models of interest: constant, linear, quadratic, cubic, asymptotic, and logistic (see Supplementary material I section 6.1.4 for equations and example plots). The models of interest are derived from previous studies examining habit strength trajectories of habit formation (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010), with the exception of the cubic model, which was a novel addition. The cubic model parameters and flexibility are similar to the quadratic and additionally estimate a second bend in the trajectory. In order to univocally describe the shape of the temporal trajectory of habit strength, the autoregressive parameter of habit strength was not included in the models.

The best fitting model for each participant was determined by the lowest Bayesian Information Criterion (BIC) index. The BIC index was used to prioritize correct model selection, as opposed to the Akaike Information Criterion, which is better suited for predicting future observations (Chakrabarti & Ghosh, 2011). Person-specific time series and fitted values were visually inspected to assess model properties and potential misfits (Wagenmakers et al., 2021). Visual inspection indicated substantial variation in how well fitted values described the observed habit strength trajectories. Accordingly, a 4-step procedure was devised to identify whether the model fitted values provided a valid description of the habit trajectory (henceforth referred to as valid fitted values). This procedure entailed (1) identifying decreasing trajectories, where (2) model selection is not impacted by individual observations, (3) the model root-mean-square-error is ≤ 0.33, and (4) the time series do not contain missing gaps of observations longer than 21 days in length. For further details about this procedure, see Supplementary material I section 6.1.4.

Subsequently, for cases where fitted values were deemed valid, time for habit decay to stabilize was calculated in two ways. For time series where the best fitting model was either the asymptotic or logistic, time for habit decay to stabilize was calculated as time needed for 95%

of the (lower) asymptote to be reached (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010). For time series where the best fitting model was either linear, quadratic, or cubic, a tentative indication of stabilization was operationalized as time until the overall change in habit strength over a 7-day period was smaller than 0.1 (explorative operationalization not stated in coregistration). A decreasing trend in habit strength that crossed the scale midpoint (before stabilization) was taken as an indication that a substantial change in habit strength is likely to have occurred, as similarly done in habit formation research (Keller et al., 2021). Time for habit decay to stabilize was estimated exclusively within the observed time series (no extrapolation).

2.2.6 Group-level models

The same six previously specified models (except the logistic model; removed because of issues with fitting the model) were used in multilevel modelling. Multilevel modelling is a well-suited approach for dealing with the nested data structure (here daily habit strength observations nested within participants) and data dependencies. Multilevel modelling allows for estimation of the average trajectory (fixed effects) and variation across individuals (random effects) (Peugh, 2010). Here time was rescaled (varying from 0 to 1.72) to improve model convergence. Random intercepts and slopes were added to the models iteratively (from lower order to higher order where applicable), and the best-fitting multilevel model was determined with the BIC index. Differences in habit decay between the four health-risk groups were inspected in two ways: (1) by adding group-level random effects and (2) by adding interaction terms (separately) to the best fitting multilevel models.

2.3 Results

A total of 194 participants were retained for analyses. Participants retained for analysis and those excluded did not differ based on sociodemographic characteristics. See Supplementary material I section 6.2.1 for flow diagram of participant retention and information on comparison between the retained and excluded samples. For analysed participants, the total number of missing SRBAI values across participants included for analysis was 4723 (29%; out of maximum 16,296). Imputation substituted one quarter of all missing SRBAI values (k = 1229) across all participants, with on average 6.3 values (range 0–20) being imputed for each participant. There was not a significant difference in percentage of missing values or longest missing gap between the behavioural groups. For more descriptive information on missing SRBAI values, see Supplementary material I section 6.2.2.

2.3.1 Sociodemographic and baseline characteristics

The sociodemographic characteristics of the sample retained for analysis (n = 194) are displayed in Table 1 (for comprehensive baseline characteristics, see Supplementary material I section 6.2.1). Overall, the median age of the sample was 39 (interquartile range 32–49) and predominantly identified with female gender (75%). The majority of the sample had completed vocational training or university studies (87%) and were employed (80%). Post-hoc pairwise behavioural group comparison on baseline characteristics revealed that the sedentary behaviour and unhealthy snacking groups were younger and had a higher proportion of women than the alcohol consumption group. Likewise, the sedentary behaviour group was significantly younger than the smoking group.

The sedentary behaviour group spent a median of 9 h sedentary per day (interquartile range 7–10 h; n = 46). The unhealthy snacking group ate a median of 14 unhealthy snack portions per week (interquartile range 10–21 portions; n = 56). In the alcohol consumption group, the median number of units of alcohol per week was 12 (interquartile range 8–29 portions; n = 52). The smoking group consumed a median of 105 tobacco product units (e.g. cigarettes) per week (interquartile range 70–140 cigarettes; n = 39).

Based on the Day 7 survey, there was a group difference in initial habit strength, whereby the sedentary behaviour and smoking groups both displayed significantly stronger habits than both alcohol and snacking groups. Participants reported having strong intention towards reducing their habitual target behaviour in response to encountering their cue. Overall, the most commonly selected habit decay strategy (based on multiple choice selection) was substitution (58%, n = 113), followed by inhibition (35%, n = 68). Here, the smoking group differed from the sedentary and alcohol groups. Substitution was clearly preferred in the sedentary behaviour (78%, n = 36) and alcohol consumption (65%, n = 34) groups, followed by inhibition (15% and 27%, respectively). In the smoking group, inhibition was selected most often (62%, n = 24), followed by substitution (28%, n = 11). The cues selected by participants referred to physical and social contexts, emotions/cognitions, and events/temporal contexts (see Supplementary material I section 6.2.1).

2.3.2 Person-specific habit decay models

All six models of interest converged for all 194 participants in person-specific modelling. Based on the BIC index, the asymptotic and logistic models were the most common best fitting models, followed by the polynomial cubic and quadratic models, with the constant and linear models being least frequently the best fitting models. There was no significant difference in the distribution of best-fitting models by behavioural group (see Table S1.4 in section 6.2.3). For descriptive statistics on best-fitting person-specific models and related sensitivity analyses, see Supplementary material I section 6.2.3. The sensitivity analyses largely confirmed results.

We identified 5 linear (26%), 4 quadratic (17%), 14 cubic (45%), 28 asymptotic (54%), and 32 logistic (60%) best-fitting models to have valid fitted values of the habit trajectory. Regarding the constant model, predicting habit to be stable over time was deemed valid for six participants (43%). See Figure 3 for examples of person-specific model plots.

Time for habit decay to stabilize ranged from 1 to 65 days (median 9–10 days; n = 42) based on asymptotic and logistic model fitted values reaching 95% of the lower asymptote within the observed time series for cases where fitted values crossed the scale midpoint. Comparatively, for linear and polynomial models, a similar range of time needed for habit decay to stabilize was observed (see Table 2).

Because this was the first intensive-longitudinal study of habit decay, we explored how habit strength varied in relation to cue-behaviour performance. This exploration suggested that habit strength is distinct from cue-behaviour performance and that there is an idiosyncratic association between the two. The visual analyses shown in Supplementary material I section 6.2.5 show that for some participants, habit gradually decreased while the behaviour was consistently not performed at cue encounter. Other participants showed no changes in habit

strength at no performance or less visible associations between cue-behaviour performance and habit strength.

Table 1. Sample characteristics by behavioural group (N = 194).

	N	Overall	SB, *n* = 46	US, *n* = 57	AC, *n* = 52	TS, *n* = 39	*p*
Baseline variables							
Age	194	39 (32, 49)	34 (30, 42)	38 (30, 45)	44 (36, 53)	40 (34, 51)	<0.001
Gender	183						<0.001
female		137(75%)	37(84%)	49(89%)	24(51%)	27(73%)	
male		45(25%)	6(14%)	6(11%)	23(49%)	10(27%)	
other		1(0.5%)	1(2.3%)	0(0%)	0(0%)	0(0%)	
BMI	183	23.5 (21.8, 27.5)	22.1 (20.8, 25.3)	24.8 (21.9, 27.9)	24.7 (22.0, 27.9)	23.5 (22.0, 26.6)	0.109
Day 7 variables							
SRBAI	194	3.00 (2.25, 3.50)	3.63 (3.25, 4.00)	2.50 (2.25, 3.25)	2.25 (1.69, 2.75)	3.25 (3.00, 3.75)	<0.001
Intention	194	3.50 (3.00, 4.00)	3.25 (3.00, 4.00)	3.00 (3.00, 4.00)	3.00 (3.00, 4.00)	4.00 (3.00, 4.00)	0.367
Decay strategy	194						<0.001
substitution		113(58%)	36(78%)	32(56%)	34(65%)	11(28%)	
inhibition		68(35%)	7(15%)	23(40%)	14(27%)	24(62%)	
discontinuation		13(6.7%)	3(6.5%)	2(3.5%)	4(7.7%)	4(10%)	

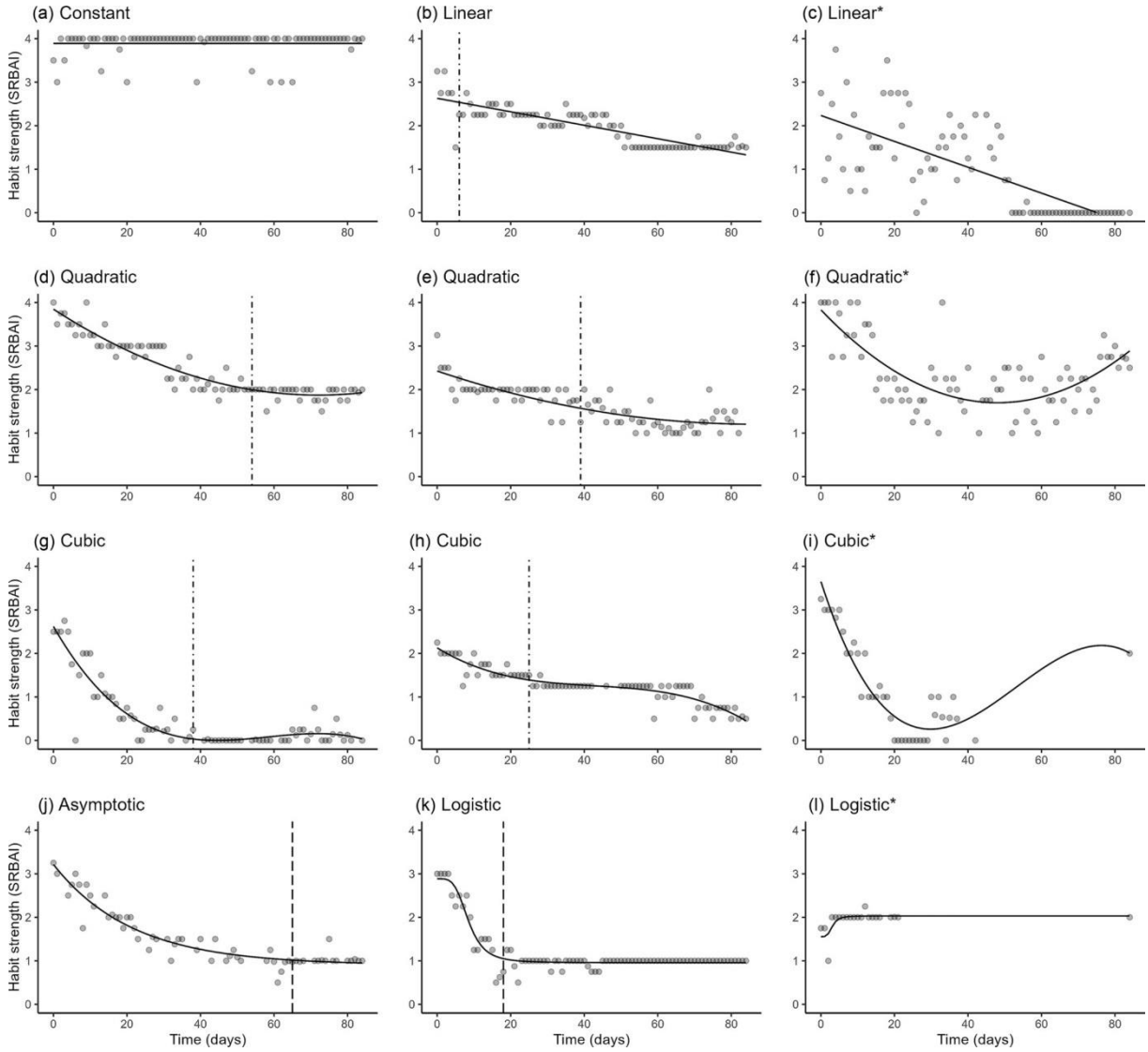
Note. Continuous variables reported with Median (interquartile range) and p-values based on Kruskal-Wallis rank sum test; Categorical variables reported with n(%) and p-values based on Fisher's Exact Test for Count Data with simulated p-value (based on 2000 replicates); SB: Sedentary behaviour; US: Unhealthy snacking; AC: Alcohol consumption; TS: Tobacco smoking; BMI: Body Mass Index; SRBAI: Self-Report Behavioural Automaticity Index

Table 2. Median (min, max) estimates of time in days for habit strength to decrease below scale midpoint and alternative definitions for habit decay to stabilize by best fitting models (n = 60).

Operationalisation	Asymptotic (*n* = 21)	Logistic (*n* = 25)	Linear (*n* = 3)	Quadratic (*n* = 4)	Cubic (*n* =7)
Decreases below scale midpoint	2 (1, 27)	2 (1, 54)	62 (41, 79)	14.5 (8, 54)	5 (1, 16)
Stabilizes[b] for 7 days	19 (7, 51)	11 (6, 29)	6 (6, 6)	41.5 (6, 54)	30 (21, 38)
Reaches 95% of lower asymptote	10 (1, 65)[c]	9 (3, 52)[d]	N/A	N/A	N/A

Note. Estimates are based on best-fitting person-specific model predictions with (1) decreasing trends, (2) stable model
selection, (3) RMSE value ≤0.33, (4) missing gaps of observations ≤21 days, and (5) predictions cross the value 2.
Abbreviation: N/A, not applicable.
[a] Sample size based on described selection procedure.
[b] Stabilization defined by first occurrence when change in model fitted values is <.01 during 7-day period.
[c] n = 19.
[d] n = 23.

Figure 3. Examples of person-specific time series with best-fitting constant, linear, quadratic, cubic, asymptotic, and logistic models ($N = 12$).



Note. SRBAI = Self-Report Behavioural Automaticity Index; grey points = observations; black lines = model fitted values; dot-dashed vertical lines = first occurrence when change in model fitted values is <.01 during 7-day period (b: 6, d: 54, e: 39, g: 38, h: 25 days); dashed vertical lines = time when 95% of the lower asymptote is reached (j: 65, k: 18 days); *model fitted values deemed nonvalid.

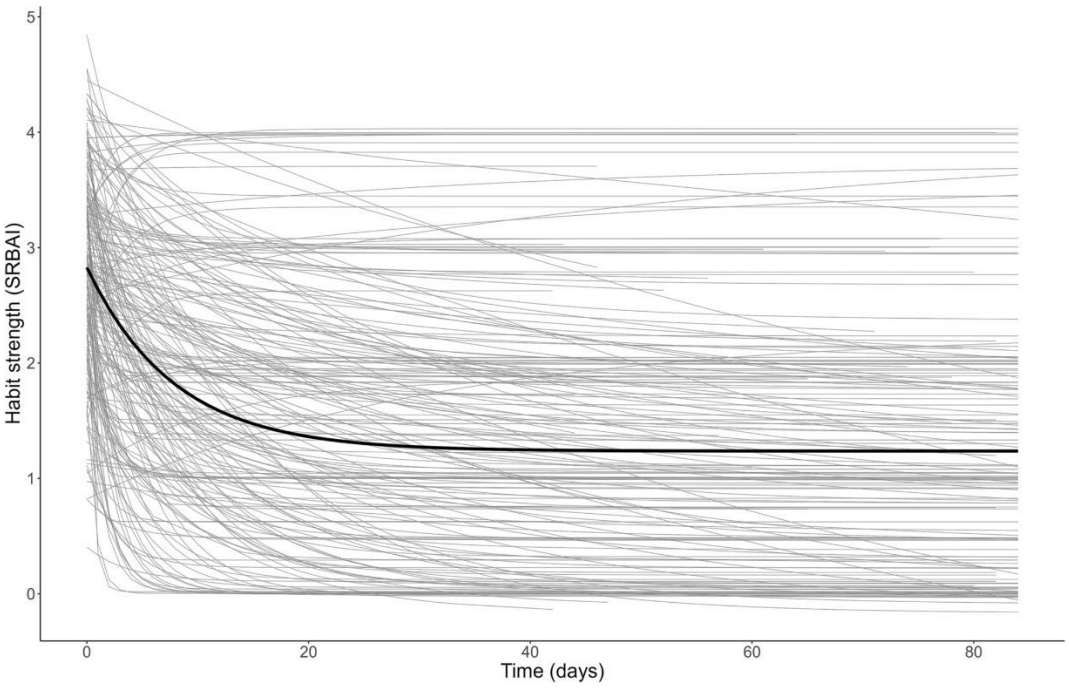
2.3.3 Group-level modelling

The intraclass correlation coefficient of the constant model suggested 76% of variance was due to between-person differences. The model displaying the best fit was the asymptotic model with between-person random effects estimated for all parameters. Results indicated that on average habit strength decreased with a decelerating trend, with substantial between-person variance evident (see Figure 4 below and Table S1.10 in section 6.2.7). Estimation issues were encountered with the asymptotic model, suggesting challenges in obtaining accurate standard errors and confidence intervals. The second best-fitting multilevel model was the cubic with

random effects estimated for all parameters, and no estimation issues were encountered. The curves of the asymptotic and cubic model fixed effects were similar in shape (see Figure S1.4 in section 6.2.6).

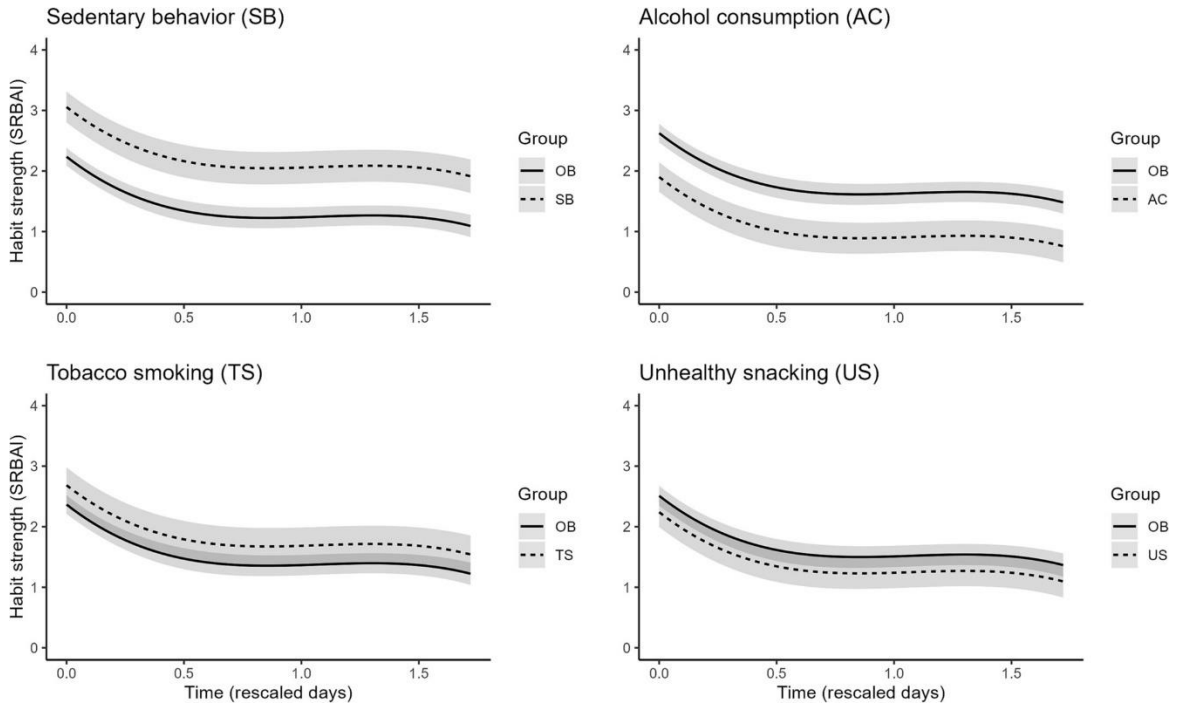
To address behavioural group differences, the asymptotic and cubic models were both used. First, behavioural group differences were investigated by adding random effects for the behavioural groups to the asymptotic model. Indicating group differences, the results suggested that allowing for group variation in initial habit strength improved model fit (see Table S1.10 in section 6.2.7). Second, group differences in the habit decay trajectory were investigated by adding interaction terms. For this analysis, we used the cubic instead of the asymptotic model due to convergence issues and limited capacity to modify parameters with the latter. We added main effects of behavioural group and interaction terms of behavioural group and time to the model. Separate multilevel models were run for each behaviour, accounting for behavioural groups with dichotomous variables indicating group membership. The models showed no indication of differences in habit trajectories between the four behavioural groups. However, findings corroborated the results of the asymptotic model in that model fit improved when allowing the intercept to vary by behavioural group. Cubic model parameters indicated that initial habit strength was higher for sedentary behaviour (β_0 =3.06, CI_{95} range 2.77–3.35) and lower for alcohol consumption (β_0 =1.90, CI_{95} range 1.62–2.17) compared with the combined averages of the other behaviour groups (β_0 =2.24, CI_{95} range 2.09–2.38 and β_0 =2.62, CI_{95} range 2.47–2.78, respectively). See Figure 5 plots for depiction of behaviour group differences. Of note, cubic model diagnostics suggested residuals to be autocorrelated. See Supplementary material I section 6.2.7 - .8 for further information on multilevel modelling results and related sensitivity analyses. Sensitivity analyses largely confirmed results.

Figure 4. Asymptotic multilevel model predicting habit strength by time (*N* = 194).



Note: The black line represents the fixed effect fitted values, and the grey lines represent person-specific fitted values. SRBAI = Self-Report Behavioural Automaticity Index.

Figure 5. Multilevel cubic model plots with main effect for behavioural group (N = 194).



Note: OB = other behaviours average effect; SRBAI = Self-Report Behavioural Automaticity Index. Time (Days 0–84) has been rescaled to vary from 0 to 1.72.

2.4 Discussion

This study investigated the trajectories of habit decay in real-world settings of people who tried to degrade a habit at the example of four health-risk behaviours. Based both on person-specific and multilevel models, habit decay is often a process where the initial decrease in habit strength is faster and gradually approaches a steady state after some time. Multilevel analysis of behavioural group differences suggested that initial habit strength may be higher for sedentary behaviour and lower for alcohol consumption. Behavioural group differences in the trajectory of habit decay were not identified, with results rather highlighting the idiosyncratic nature of this process.

2.4.1 How does habit strength decrease over time?

Present findings are in line with habit formation research suggesting change in habit strength to be typically described by non-linear processes of change with pronounced interindividual differences (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Lally et al., 2010; Van Der Weiden et al., 2020). These observed interindividual differences are subsequently described. First, habit strength may decrease in a decelerating fashion such that it ultimately reaches a newfound stable state. This is evident and explicitly estimated by asymptotic and logistic models (see Figure 3 j, k). Furthermore, this was tentatively visible for some polynomial models (see Figure 3 d, e, g), as comparatively concluded in the context of habit formation (Keller et al., 2021). When decay and stabilization occur rapidly, this may be

termed habit disruption. Second, habit strength may decrease without clear stabilization at a lower bound (see Figure 3 b, h) based on linear and polynomial model estimates. Third, findings show that the lower bound that habit strength approaches may differ between individuals (e.g. comparing Figure 3 d, h, j).

Idiographic modelling also showed that habit decay may be unsuccessful in various ways. First, in some instances, a habit retained its strength over time (e.g. Figure 3 a), which can be described as a stable, strong habit (Rebar et al., 2022). Second, in some instances, habit gained strength over time (e.g. Figure 3 l). Habit strengthening may be an indication of relapse to a habitual tendency that precedes the observed time series. Third, in some instances, habit strength initially decreased but subsequently regained strength (see Figure 3 f, i). This discontinued change process is captured by a U-shaped curve of polynomial models, as also comparatively suggested in the context of habit formation (Keller et al., 2021).

2.4.2 How long does it take for habit decay to stabilise?

Based on the time needed for 95% of the lower asymptote to be reached within the observational period (n = 42; 22% of sample), habit decay stabilization typically took under 2 weeks, ranging from 1 to 65 days (see Figure 3 j, k). Regardless of whether habit decay is better described by the asymptotic or logistic model, habit strength reaches the lower bound within similar periods of time (Table 2). Estimates of time for habit decay to stabilize based on linear and polynomial models were similar, although interpretation warrants caution as the operationalization is less stringent. For example, estimating the time for habit decay to stabilize based on when the change in habit strength during a 7-day period is less than 0.1 seems to perform well when habit strength initially decreases rapidly and later slows down (see Figure 3 d, g), but less optimally when the decrease is more gradual (Figure 3 b, e) or includes a transient phase of stabilization (Figure 3 h).

Interpretation of findings indicating short duration of habit decay stabilization (e.g. 1 day) warrants caution. This very short duration is not in line with habit theory, which suggests that habits take time to change. Potentially, this short duration is linked to issues of measurement validity (see section 2.4.5). Also, decay stabilization does not necessitate that the habit has been "broken." It is further important to note that a comparison of durations in habit decay and habit formation processes is difficult due to differences in procedures. Habit formation studies have reported a median of approximately 60 or more days for habits to form (Keller et al., 2021; Lally et al., 2010). However, habit formation studies utilized different procedures, including constraining cue-behaviour repetition to once per day and extrapolation of model predictions beyond the observed time series.

2.4.3 Behavioural differences

Multilevel modelling highlighted that substantial variance in habit decay trajectories is largely due to differences between individuals and that this between-person heterogeneity is larger than target behaviour-related differences. Nonetheless, multilevel modelling results indicated that habits for sedentary behaviour exhibit greater initial strength and that habits for alcohol consumption exhibit lower initial strength compared with the other behaviours studied (see Figure 5), as also indicated by baseline behavioural group comparisons (see Table 1). These differences in initial habit strength may reflect random variation in sampling or a systematic

difference between the target behaviours. It could be that the stronger initial habit observed for sedentary behaviour is due to a higher frequency of cue-behaviour repetition in the past. As similarly discussed in the context of the relative ease in establishing hand-washing habits (Buyalskaya et al., 2023), present findings of strong initial habit strength for sedentary behaviour may be linked to the fact that this behaviour is frequently enacted and part of chunked action sequences (Balleine & Dezfouli, 2019).

2.4.4 Strengths and limitations

The present study bears several strengths in terms of procedures and data analysis. Importantly, this is the first study to investigate habit decay in daily life with intensive longitudinal data. Sampling from the general population, intensive longitudinal assessment, and allowing participants to select personally relevant cues informed by an observational period enabled ecologically valid investigation. In terms of statistical practice, extensive data visualization and diverse modelling approaches align with practices promoting transparency and acknowledgment of uncertainty (Wagenmakers et al., 2021).

The study naturally also has limitations. First, measuring the perception of automaticity as an indicator of habit strength is constrained because habit operates outside of conscious awareness (Gardner & Tang, 2014; Hagger et al., 2015). Second, although sampled from the general population, the convenience sample consisted of highly educated individuals with strong intention towards breaking their habit, which sets limitations to the generalizability of results. Third, the procedures to identify model-fitted values as valid used cut-off scores. While these cut-offs are arbitrary and do not perform optimally across all trajectories, this approach allowed for systematic classification not prone to subjective bias. Fourth, multilevel modelling was restricted by estimation issues. The logistic model was not used in multilevel modelling, and the asymptotic model could not be leveraged to its full potential, which is attributable to the large heterogeneity in trajectories.

2.4.5 Future directions

The present study can inform future habit research on what to expect regarding data quality and how to potentially handle and interpret similar intensive longitudinal data. Findings demonstrate that idiographic approaches provide a more detailed understanding of the heterogeneous habit change processes compared with nomothetic approaches. Additionally, the study illustrates how accounting for missing gaps (see Figure 3 i, l) and model absolute fit (see Figure 3 c, f) play complementary roles in determining model accuracy, providing insights into the boundaries of intensive longitudinal modelling and the confidence in evidence of such modelling efforts. Findings also highlight how isolated observations following a long missing gap may impact model selection and lead to potentially inaccurate models (see Figure 3 i). Relatedly, we posit that estimation of time for habit decay to stabilize strictly within the observed time series provides a stronger evidence base compared with incorporating extrapolation of model predictions.

This study provided initial evidence for the credibility of habit strength self-report measurement in the context of habit degradation by showing that habit strength is distinct from cue-behaviour performance. For example, a self-reported habit can change gradually (and not abruptly) when not performing the behaviour at the occurrence of the cue (see Supplementary material I section

6.2.5). While our exploratory findings are encouraging, more studies are needed to unveil the boundary conditions for the validity of a self-reported habit strength measurement in the context of habit decay. Habit strength being distinct from cue-behaviour performance does not rule out the potential influence of relevant experiences such as habitual behavioural slips or a lack of cue encounters (Keller et al., 2021; Sniehotta & Presseau, 2012), which may partially explain habit strength fluctuation (see Figure 3 c, f) and the speed with which habit disruption often occurred.

The field of habit research would benefit from more precisely defined criteria for self-report habit measurements as to what constitutes a habit and substantial change in habit strength. In the present study, meaningful change was (arbitrarily) defined by necessitating habit strength to cross the scale mid-point, as done previously in habit formation research (Keller et al., 2021; Lally et al., 2010), but this criterion seems insufficient. For example, change amounting to less than a one-point decrease on the Likert scale (that crosses the scale mid-point) may be appropriately described as a relatively stable process over time (see Figure 3 l). Future research should strive to observe habit decay in daily life beyond 3 months to capture how this process may be maintained over extended periods of time.

There are some preliminary recommendations for intervention studies that can be made based on the habit degradation strategies participants were guided to use. Interventionists are encouraged to leverage the substitution and inhibition strategies, as based on the uptake, these are preferred approaches compared with discontinuation (see Table 1). However, more research is needed to compare the effectiveness of alternative degradation strategies. As such research needs to account for fidelity (e.g. implementation frequency) and cue characteristics (e.g. frequency of encounters), this was beyond the scope of the present paper.

2.4.6 Conclusions

Investigating habit decay with high resolution elucidates the multitude of potential forms this temporal process may take. For future intensive longitudinal habit research, it is recommended to utilize idiographic approaches with non-linear models of change and to extensively leverage data visualization. Present findings are moderately encouraging in terms of the viability of degrading unhealthy habits with usage of implementation intentions and hold promise for the development of interventions to overcome unhealthy habitual tendencies.

Data availability statement: Core R-scripts, data, and comprehensive data visualizations are available on https://osf.io/sngu4/.

3. Manuscript II – Determinants and strategies of habit degradation: an intensive longitudinal study

This manuscript is under peer review. The article preprint is available online: Edgren, R., & Inauen, J. (2025a). Determinants and strategies of habit degradation: An intensive longitudinal study. https://doi.org/10.31219/osf.io/2xzsw_v2.

Supplementary material II contains additional information for this manuscript.

Author contributions

Robert Edgren: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization, Project administration, Data curation; **Jennifer Inauen:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – reviewing and editing

Abstract

Objectives: Unhealthy habits can pose a barrier to health behaviour maintenance, yet little is known about the determinants or strategies of habit degradation. We explore the role of person, cue, and behaviour related determinants, alongside different habit degradation strategies using implementation intentions (II) for habit degradation. **Methods and Measures:** Participants (*N* = 194) formed IIs for self-selected strategies (substitution, inhibition or cue discontinuity) to degrade a habit (related to sedentary behaviour, unhealthy snacking, alcohol use, or smoking) over 12 weeks. Daily diaries assessed habit strength using the Self-Report Behavioural Automaticity Index and its determinants. II characteristics were qualitatively coded. Linear regression and multilevel modelling tested predictors of habit strength. **Results:** Habit strength was greater on days with cue-encounter and lower on days with non-performance of habitual behaviour and higher-than-average reward. Substitution was the most common strategy. Stress and intention were significant in some models. No significant associations were found for strategy type or II characteristics. **Conclusion:** Non-performance of the habitual behaviour and reward emerged as determinants of habit degradation, while encountering habitual cues might counteract degradation efforts. Although strategies did not differ in impact, preference for substitution may reflect higher feasibility than inhibition and cue discontinuity. Experimental replication is warranted.

3.1 Introduction

Physical activity, diet, alcohol and tobacco use are central factors of non-communicable disease and premature death (Muller et al., 2016), highlighting the need for longstanding behaviour change. Achieving long-term change in turn may require degrading preexisting unwanted habits (Gardner et al., 2021). *Habit* is defined as the mental representation of a cue-behaviour association learnt through the repeated pairing of the two, and that is characterised by automaticity (Fleetwood, 2021; Moors & De Houwer, 2006). For example, "drinking morning coffee" may be a cue for smoking. Here, smoking that occurs after a cue encounter is *habitual behaviour,* i.e. behaviour performed due to an underlying habit (Gardner & Lally, 2023). To intervene on habits, it is important to have a comprehensive understanding of the relevant determinants. While research on habit formation has made considerable progress on this, less is known about the determinants and strategies of habit degradation (Gardner et al., 2023).

3.1.1 Determinants of change in habit strength

In the absence of research on the determinants of habit degradation (sometimes referred to as habit decay, e.g. Tobias, 2009 or habit disruption, e.g. Gardner et al., 2021), we turn to the literature on habit formation to draw hypotheses. In habit formation research determinants of habit strength have been conceptualized as person, cue and behaviour related factors (Gardner et al., 2023; Gardner & Lally, 2018). The determinants of habit formation are likely to have counterparts in the context of habit degradation, as subsequently described. Thereafter, a conceptual framework (Figure 6) is presented that contextualizes the determinants of change in habit strength into the processes of habit degradation.

Person related factors. Theorized person related determinants of habit formation include factors such as motivation, self-control, intention and stress (Gardner et al., 2024; Gardner & Lally, 2018). Self-control has been shown to be negatively associated with habit strength (Adriaanse et al., 2014) and motivation, intention and stress have shown to be positively associated with habit formation (Giovanniello et al., 2023; Judah et al., 2018; Orbell & Verplanken, 2010; Radel et al., 2017; Schwabe & Wolf, 2009). In contrast to habit formation, wilfully abstaining from habitual behaviour is less likely to occur when self-control is depleted (Neal et al., 2013) or stress is experienced (Fournier, d'Arripe-Longueville, & Radel, 2017). Furthermore, intention to perform non-habitual behaviours may promote habit degradation by instigating cognitive inhibition (Danner et al., 2011).

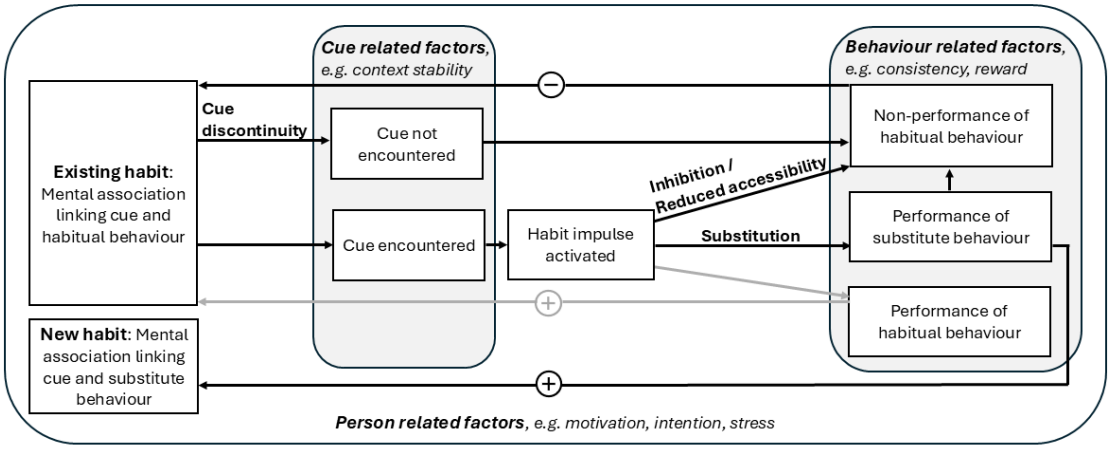
Cue related factors. Theorized determinants of habit formation related to cues (Gardner & Lally, 2018) include context stability (e.g. encountering cue at recurring time and location), and effective salience (i.e. unacquired attribute of cue being easily perceived) (Esber & Haselgrove, 2011). Context stability has been shown to be positively associated with habit strength in humans (McCloskey & Johnson, 2019; Pimm et al., 2016), while cue salience has been shown to be associated with habit formation in rats (Thrailkill et al., 2021). There is limited literature on cue related factors in habit degradation, but it is conceivable that cues with high context stability may facilitate planning for non-performance of habitual behaviour. It is also feasible that cue properties, such as being linked to external (e.g. lunch) or internal environment (e.g. emotions), influence the habit degradation process but this remains to be investigated.

Behaviour related factors. Theorized behaviour related determinants of habit formation include the reward value and complexity of the behaviour, and the consistency of cue-behaviour repetition (Gardner & Lally, 2018). Longitudinal studies have shown perceived reward (Di Maio et al., 2022, 2025; Judah et al., 2018) and low complexity (Kaushal & Rhodes, 2015) to be associated with habit formation. Higher consistency in cue-behaviour repetition has been shown to be associated to habit formation (Keller et al., 2021). Similarly, in the context of habit degradation it may be that consistent non-performance of habitual behaviour is key to degradation (Gardner et al., 2023; Tobias, 2009), but evidence is limited in this regard. Concerning degradation and reward, it is suggested that alternative actions that hold comparable or stronger reward value than the unwanted habitual behaviour are more likely to enable habit degradation than less rewarding alternatives (Gardner et al., 2021). In acknowledgement of potential behaviour related determinants, it is conceivable that the habit degradation process may differ between behaviours that are distinct in terms of related determinants. Interestingly, habit degradation was not found to differ between sedentary behaviour, unhealthy snacking, alcohol consumption or smoking (Edgren et al., 2024) leaving open questions as to what may be relevant behaviour related determinants of degradation.

3.1.2 Habit degradation strategies

The outcome of efforts to degrade a habit may depend on the strategies used to pursue degradation. Conceptually three strategies were initially recognized (substitution, inhibition, cue discontinuity) (Gardner et al., 2021) until more recently reducing behavioural accessibility was distinguished as a fourth strategy (Gardner et al., 2024). Substitution entails replacing an existing habit by performing a substitute behaviour following a cue encounter (e.g. drinking water instead of wine with dinner) (Gardner et al., 2021, 2024). Inhibition entails refraining from performing habitual behaviour following a cue encounter (e.g. by motivational self-talk) (Gardner et al., 2024; Quinn et al., 2010). Reducing behavioural accessibility is a specific form of inhibition driven by restricting opportunities (e.g. removing alcohol from home). Finally, cue discontinuity entails limiting cue encounters (e.g. avoiding bus stop that triggers habitual smoking) (Gardner et al., 2024; Walker et al., 2015). In cases where the cue is the object of the habitual behaviour (e.g. seeing sweets in the kitchen), then cue discontinuity and reducing behavioural accessibility overlap. It is theorized that substitution is superior in intervening on habit, due to directly targeting the underlying cue-behaviour association, while the other strategies merely target habitual behaviour (Gardner et al., 2021, 2024). Relatedly, substitution of commuting habits has been shown to decrease habit strength of the old commuting habit (Di Maio et al., 2025; Walker et al., 2015). However, conceptually the case can also be made that other strategies can degrade a habit as well. Specifically, if non-performance of habitual behaviour at the occurrence of the cue is a determinant to habit degradation as theorized (Tobias, 2009), this implies that strategies other than substitution can also degrade habit strength (see Figure 6). However, empirical evidence is scarce regarding whether the strategies differ in their ability to degrade habit strength (Gardner et al., 2023). Interestingly, a recent pilot trial found that both inhibition and substitution of pre-sleep electronic device use reduced habit strength from baseline to follow-up three weeks later (Hill et al., 2025), which suggests strategies other than substitution can indeed degrade habit strength.

Figure 6. Conceptual framework of habit degradation and its determinants and strategies



*Note***.** This framework builds upon previous work by Gardner & Lally (2018) and Gardner et al. (2024). Black arrows represent the processes of degrading a habit by discontinuation of cue encounters, inhibition, reduced accessibility and substitution. Substitution has a twofold effect of degrading an existing habit and forming a new habit. Degradation strategies can be operationalized with implementation intentions. Grey arrows represent the process of maintaining an existing habit. Habit degradation is theorized to be influenced by various determinants broadly noted as person, cue, and behaviour related factors. Factors may be conceptualized and/or measured as time varying or invariant.

Using a degradation strategy can be achieved with implementation intentions, which are context specific if-then plans (Gollwitzer, 1993), and previous research has shown this to be a viable approach (Adriaanse & Verhoeven, 2018; Armitage, 2016; Edgren et al., 2024). Recent time series analysis of habit strength (Edgren et al., 2024) demonstrated that when degradation strategies are operationalized through implementation intentions, habit strength can be weakened. To advance habit research, it is essential to compare the effectiveness of different strategies. Importantly, such comparisons should account for the occurrence of implementation intention enactment. Additionally, the characteristics of implementation intentions, such as if-then sentence structure, number of implementation intentions formulated and the response type (e.g. behavioural or cognitive) may be moderating factors of their effectiveness (Prestwich et al., 2015), but this remains unexplored in habit research.

3.1.3 The present study

To address the outlined research gaps in the field of habit degradation, this study builds upon our previous work, where extensive univariate time series analysis of habit strength was conducted to further our understanding of the temporal dynamics of habit degradation (Edgren et al., 2024). We now extend this work by investigating the determinants, strategies and implementation intention characteristics of habit degradation. Specifically, this study exploratively investigates which person-, cue-, and behaviour- related factors are the determinants of habit degradation. Further, we investigate which strategies of habit degradation relate to greater decreases in habit strength in the context of an attempt to degrade a health-related habit. Finally, we will investigate the characteristics of the implementation intentions

formulated to operationalize the habit degradation strategies as determinants of habit degradation. As examples, we are focusing on habits related to four health-risk behaviours: sedentary behaviour, unhealthy snacking, alcohol and tobacco use.

3.2 Materials and methods

We performed secondary analyses of a 91-day intensive longitudinal study with four parallel non-randomized groups of participants who self-selected to change a habit related to one of four health-risk behaviours (sedentary behaviour, unhealthy snacking, alcohol consumption, or tobacco smoking) (Edgren et al., 2024). The analysis plan for this study was coregistered (Benning et al., 2019) prior to analysis, and is available online (https://osf.io/g6wpr). The ethics committee of the authors' faculty granted ethical approval for the study. ChatGPT-4 (OpenAI, 2025) was used in preparation of this manuscript to improve concise wording of selected text passages.

3.2.1 Population and sample

Sampling was conducted from the adult German speaking Swiss population. Eligibility criteria included age of at least 18 years, smartphone ownership, willingness to reduce the habit for one of the four target behaviours, and providing informed consent. Additionally, participants needed to complete the Day 7 survey of the study to proceed with participation (see Figure 7). Finally, participants who provided at least 6 habit strength responses overall, and who reached at least halfway through the habit degradation phase (Day 48) were included in analyses.

The planned sample size of 200 (Edgren et al., 2024) was based on simulation-based recommendations (Arend & Schäfer, 2019), suggesting that, to achieve statistical power of .80 in a two-level model with a small effect for time, a medium effect for between-person differences, and a large intraclass correlation coefficient, a sample of this size is adequate. The present secondary analyses are conducted with the same sample included in primary analyses (N = 194). The mean age of this sample was 41 years, 75 % identified with female gender and initial habit strength was above the scale midpoint (M = 3; interquartile range 2.25-3.50) (Edgren et al., 2024). Overall, across all participants (N = 194) the data included 11767 habit strength observations (29 % missing). For further information on sampling, attrition and compliance please refer to the primary publication (Edgren et al., 2024).

3.2.2 Measures

All measures were self-reported. See Figure 7 for chronology of measurement and supplementary file for additional details on item wording. The primary outcome habit strength was measured with a German adaptation of the Self-Report Behavioural Automaticity Index (SRBAI) (Gardner et al., 2012; Verplanken, 2007) on a 5-point Likert scale (scored 0-4). SRBAI items were personalized, referencing performance of the target behaviour after encountering the self-selected cue (e.g. "*Drinking alcohol in the situation (watching TV at home) is something that I do without thinking about it*"). The habit strength scale showed excellent between-person reliability (R_{kRn} = 1.00) and moderately high within-person reliability (R_{cn} = 0.78) in the present data (Cranford et al., 2006; Shrout & Lane, 2011).

Person related factors. *Autonomous and controlled motivation* to reduce (or try to reduce) the target behaviour was measured with 12 items from the Treatment Self-Regulation

Questionnaire (TSRQ) on a 7-point Likert scale (with higher values indicating higher autonomous/controlled motivation). The subscales for autonomous and controlled motivation were based on the mean of corresponding items (Levesque et al., 2006; Ryan & Connell, 1989).

Dispositional self-regulation (i.e. not related to target behaviour) was measured with the 7 item Self-Regulation Scale (SRS) (Luszczynska et al., 2004) on a 4-point Likert scale (with higher scores indicating higher self-regulation) and composite score calculated with the mean of the items.

Next day *intention* (De Bruijn et al., 2012; Edgren et al., 2024) to reduce performance of habitual behaviour and *perceived stress* (S. Cohen et al., 1983; Schneider et al., 2020) were both measured with two 5-point Likert scale items each (scored 0-4; higher values corresponding to higher level of corresponding construct), and composite scores calculated for each construct with the mean of the items. In the current data, the intention scale showed excellent between-person (R_{kRn} = 0.99) and within-person (R_{cn} = 0.90) reliability, while the perceived stress scale showed excellent between-person (R_{kRn} = 0.98) and moderate within-person (R_{cn} = 0.64) reliability (Cranford et al., 2006; Shrout & Lane, 2011).

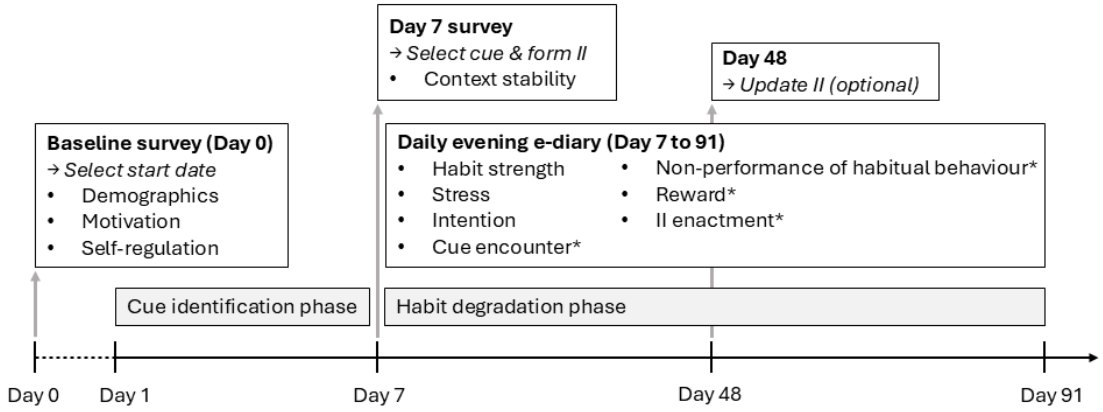
Cue related factors. *Context stability* was measured with 4 items (5-point Likert scale; scored 0-4) measuring stability of mood, time, place and people (Gardner & Tang, 2014). Context stability items referenced performance of habitual behaviour (e.g. "*When I am smoking in my selected situation (drinking morning coffee) I am* [never / rarely / sometimes / most times / always] *in the same mood*").

Cue encounter was assessed with "*Have you experienced the (cue) situation you chose today?*", with multiple choice responses options: no, once, several times. Responses were dummy coded for analysis (0 – no cue encounter, 1 – at least 1 cue encounter). The self-selected cue chosen by participants on day 7 was categorized as related to the physical context, social context, emotion / cognition, and/or event/action as part of the qualitative analysis. Details on the qualitative analysis are provided below (section Habit degradation strategy and implementation intention).

Behaviour related factors. *Non-performance of habitual behaviour* was assessed if participants affirmed a cue encounter on that day with e.g. "*Did you eat unhealthy snacks in the situation you selected (coffee break at work)?",* with responses (multiple choice options if one cue encounter: no / yes; if more than 1 cue encounter: no / sometimes / always) dummy coded for analysis (0 – performance of habitual behaviour, 1 – non-performance of habitual behaviour).

Perceived reward from reducing habitual behaviour (Di Maio et al., 2022; Wiedemann et al., 2014), was measured using two 5-point Likert scale items "*Reducing* [target behaviour] *in my selected situation* ([cue]) *feels rewarding to me.*" and "*Reducing* [target behaviour] *in my selected situation* ([cue]) *is something I like to do.*" (scored 0-4; higher values corresponding to higher level of the construct), and composite scores calculated with the mean of items. The perceived reward scale displayed excellent between-person (R_{kRn} = 0.98) and moderately high within-person (R_{cn} = 0.81) reliability (Cranford et al., 2006; Shrout & Lane, 2011).

Figure 7. Overview of study procedures



*Note***.** Selected overview of procedures relevant to present analyses. Content following right pointing arrows (→) indicate key procedural instructions given to participants. Bullet points indicate constructs measured, which are time-invariant for surveys and time-varying for e-diary. II: Implementation intention; *Included in e-diary from Day 8.

Habit degradation strategy and implementation intention. Participants were introduced to habit degradation strategies and guided to formulate an implementation intention according to the preferred strategy (see Procedures section below). Information on the habit degradation strategy used and implementation intention characteristics were derived by conducting a qualitative analysis with a coding scheme developed for this purpose. The coding scheme enabled labelling implementation intentions according to the correct strategy. Manual coding of degradation strategy was necessary because the selected strategy and actual strategy used in the implementation intention were not necessarily congruent. Furthermore, coding characteristics of implementation intentions is relevant, as a range of characteristics such as if-then format, nature of the cue and response type have been shown to be associated to a range of outcomes (Sheeran et al., 2025).

The coding scheme (see Supplementary material II section 7.2) was developed based on a previously developed coding scheme created to evaluate implementation intentions (Warner et al., 2022), the taxonomy of implementation intentions (Prestwich et al., 2015), and pretesting procedures of the present study. Interrater agreement was high for a subset of implementation intentions that were coded in duplicate, suggesting the guidelines enabled replicable coding (see Supplementary material II section 7.2.1 for further details).

The qualitative analysis identified which habit degradation strategy was used in the implementation intention (substitution, inhibition or cue discontinuity), evaluated the congruence of habit degradation strategy identified in implementation intention with selected strategy (see Procedures below), the validity of implementation intentions, and the number of if- and then- components contained within an implementation intention. Additionally, the specificity of the if- and then-components, and the then-component response type (e.g. replacing behaviour, setting limits, directing attention) were analysed. Furthermore, the coding scheme analysed whether the intended outcome of the implementation intention was to reduce

or avoid the target behaviour, whether the implementation intention was worded as a negation, usage of the words "if" and "then", the potential mismatch between the cue and if-component, and whether multiple implementation intentions were created (within same session on Day 7).

Implementation intention enactment indicates whether non-performance (or reduced performance) of habitual behaviour is achieved by following the defined implementation intention. Implementation intention enactment was measured with a single item "*Did you perform your plan today in reducing [target behaviour] in the situation you chose (selected cue)?"* (yes/no dichotomous response) with the implementation intention formulated by the participants displayed below the question.

3.2.3 Procedure

Recruitment was conducted predominantly via social media (separate ads for each behavioural group) stating habit degradation as the focal topic (Edgren et al., 2024). Participants were redirected to the baseline online questionnaire via the advertisement after providing informed consent. Subsequent surveys and e-diary questionnaires were distributed via text message to participants' smartphones. E-diary questionnaires were delivered at the participants' self-selected time in the evening (fixed interval contingent prompting).

The study consisted of one diary period that contained two distinct phases (see Figure 7). The first 7 days of the study was a cue identification phase aimed at helping participants better understand their habits and identify cues that trigger habitual behaviour (Edgren et al., 2024). On Day 7, participants were guided to select one cue to focus on for the subsequent habit degradation phase of the study and create an implementation intention using a habit degradation strategy of their choice (substitution, inhibition or cue discontinuity). To support participants in making an informed decision about strategy selection and implementation intention formulation, examples of each strategy were given followed by step-wise instructions (Edgren et al., 2024). For the subsequent 84 days participants were instructed to try to degrade their habit (habit degradation phase) and respond to end-of-day e-diary questionnaires. On Day 48, participants had the opportunity to update their implementation intention, nonetheless maintaining the cue selected on Day 7 (Edgren et al., 2024). Participants were reimbursed up to 100 CHF for taking part in the full study (or 7 CHF per week for incomplete participation).

3.2.4 Analyses

Preprocessing. Quantitative analyses were conducted with R Statistical Software version 4.3.3 (R Core Team, 2021). Online end-of-day e-diary responses given between 0:00 a.m. and 12:00 p.m. were recoded to refer to the previous day, and duplicate responses for the same day removed by averaging (Edgren et al., 2024). Missing observations from the Treatment Self-Regulation Questionnaire (n = 2; 1 %) and Self-Regulation Scale (n = 11; 6 %) scales were imputed with conditional means based on behavioural group, as singular imputation performs similarly to multiple imputation when under 10% of observations are missing (Barzi & Woodward, 2004). Imputation of missing observations for time varying variables was not performed.

Multiple linear regression predicting Day 91 habit strength. Multiple linear regression analysis was conducted to investigate the association of time-invariant predictors

with the dependent variable, habit strength at Day 91 (i.e. end of the study). Linear regression was not specified in the analysis plan coregistration. This approach was adopted to limit the number of predictors included in any single model. Time invariant person and cue related factors and implementation intention characteristics were used as predictors of habit strength at the end of the study. Initial habit strength was included as a covariate in the model to account for the extent of change in habit strength. For sensitivity analysis missing values in habit strength at Day 91 were replaced by the last observation. Significant predictors identified in multiple linear regression were to be subsequently added to the multilevel models.

Multilevel models predicting daily habit strength. To adequately account for nested data structure (days nested within individuals), estimate average effects (i.e. fixed effects) and variation between individuals (i.e. random effects) multilevel modelling was used (Edgren et al., 2024; Peugh, 2010). In this context, modelling random effects for intercepts and slopes enables accounting for individual differences in the average level of a variable and individual differences in the relationships between variables (Hamaker, 2025).

Two multilevel models predicting daily habit strength were conducted. In Model 1, predictors were time-varying person, cue and behaviour related determinants. Model 2 was an extended model which additionally included habit degradation strategy and implementation intention enactment as predictors. Lastly, as sensitivity analysis Model 2 was further extended to include behaviour group as covariates of habit strength (Model 2s). Model 1 included all participants with sufficient data (n = 188; 6 participants dropped due to missing values on every row). Models 2 and 2s were limited to include participants who consistently used the same habit degradation strategy (n = 166) throughout the study (i.e. did not change strategy on Day 48) and had sufficient data (n = 160; 6 participants dropped due to missing values on every row).

Based on extensive univariate time series analysis of the present data (Edgren et al., 2024), habit strength trajectories were detrended in the multilevel models by including cubic time predictors, and autocorrelation accounted for by including a lag-1 predictor of habit strength. Lagged habit strength was centred at initial (i.e. Day 7) habit strength. Each multilevel model controlled for the effect of initial habit strength, which was grand mean centred for analysis. Time was centred at the end of the study, when the effect of the strategies was assumed to be strongest (Day 91) and scaled to support model convergence, as recommended in the R package lme4 documentation (Bates et al., 2015).

Multilevel model time invariant predictors were grand mean centred. Time varying predictors were decomposed into between person effect (person mean), and the within person effect (person mean centred daily score) (Hoffman, 2015). Person mean centring time varying predictors enables investigation of between person differences in the mean, and within person variation of the variable (Hamaker, 2025). Next day intention was lagged for analyses to align the prospective (next day) intention with the subsequently reported habit strength. No other predictors were lagged for analysis, as same-day effects are most proximal and presumed to display the strongest associations with habit strength. Random effects (intercepts and slopes) were added to maximum capacity for time, autocorrelation and within person predictors without encountering non-convergence or singular model fit. Standardized coefficients were used to estimate effect size, and magnitude determined by Cohen's conventions (J. Cohen, 1992). To

reduce the Type I error risk due to multiple hypothesis testing, model coefficient p-values (applied to both multiple regression and multilevel models) were adjusted with the sequentially rejective Bonferroni method (Holm, 1979).

3.3 Results

3.3.1 Descriptive results

Person, cue and behaviour related factors. The sample in general displayed high autonomous and low controlled motivation for reducing their target health-risk behaviour (Table 3). The most common type of cue category was event/action (present in 53 % of cues), followed by physical context and emotion/cognition. Cues were defined by one or more categories simultaneously, which is not distinguished in Table 3. 129 participants (67 %) defined cues that included only one cue category. For cues defined by one cue category, emotion/cognition was most common (*N* = 50; e.g. *"Stress", "Craving", "Boredom"*), followed by event/action (*N* = 45; e.g. *"Lunch break", "Friday evening"*) and physical context (*N* = 29; e.g. *"Office chair", "Sweets in cupboard"*). When cues were defined by multiple cue categories (*N* = 59), this was predominantly cues defined by event/action in combination with physical context (*N* = 33; e.g. *"Watching TV", "Arriving at workplace"*), emotion/cognition (*N* = 10; e.g. *"Relaxing after a meal", "Boredom in the evening"*) or social context (*N* = 10; e.g. *"Dinner together", "Smoking breaks with colleagues"*).

Table 3. Descriptive statistics of time invariant person and cue related factors (*N* = 194).

Variable	*N*	Median (*IQR*) / *n* (%)
Person related factors		
Autonomous motivation	194	4.83 (4.17, 5.50)
Controlled motivation	194	1.75 (1.00, 2.50)
Self-regulation	194	2.00 (1.71, 2.29)
Cue related factors		
Context stability	194	
mood		3.00 (2.00, 3.00)
time		2.00 (2.00, 3.00)
place		3.00 (2.00, 4.00)
people		2.00 (1.00, 3.00)
Cue category*	188	
physical context		67(36%)
social context		18(9.6%)
emotion/cognition		64(34%)
event/action		100(53%)
unknown		6

Note. *Cue category is derived from the qualitative analysis; Motivation based on Treatment Self-Regulation Questionnaire (scale ranges 0-6); Self-regulation based on Self-Regulation Scale (scale range 0-3); Context stability items range 0-4; IQR: interquartile range (25%, 75%).

Over the course of the study, participants reported moderately high levels of intention to reduce their habitual behaviour, relatively low levels of perceived stress, and cue encounters on the majority (63 %) of days. Non-performance of habitual behaviour was more infrequent (21 %

of days), and participants reported relatively high perceived reward from reducing habitual behaviour (Table 4). The rather low values of habit strength displayed in Table 4 reflect the fact that habit strength decreased over time. Based on the intraclass correlation coefficients (ICC), over half of the variance of each predictor was explained by within-person fluctuation. By comparison, well over half of habit strength variance was explained by between person differences (ICC = 0.75). See supplementary file Figures S2.1-S2.8 in section 7.3.1 for plots depicting sample level and within-person change over time of time varying variables. Habit strength, perceived stress, perceived reward, implementation intention enactment and intention had in total approximately 29 % of missing values over the course of the study. In contrast, the variables for cue encounter and non-performance of habitual behaviour contained in total approximately 41 % of missing values over the course of the study, but this missingness was not causally related to habit strength. This higher degree in missingness was due to the e-diary questionnaire initially missing items for cue encounter and non-performance of habitual behaviour.

Table 4. Descriptive statistics of time-varying variables (*N* = 194).

	Observations	Median (*IQR*)	*ICC*
Habit strength	11767	1.52 (0.75, 2.30)	*0.75*
Person related factors			
Intention	11748	2.90 (2.27, 3.43)	0.47
Perceived stress	11772	1.04 (0.66, 1.42)	0.39
Cue related factors			
Cue encounter*	9778	0.63 (0.45, 0.85)	0.47
Behaviour related factors			
Non-performance of habitual behaviour*	9776	0.21 (0.04, 0.38)	0.47
Perceived reward	11561	2.41 (1.94, 2.91)	0.43
Planning related factors			
Plan enactment*	11575	0.58 (0.35, 0.79)	0.44

*Note***.** Median (IQR) depicts the distribution of the corresponding variable's person mean values; IQR: Interquartile range (25%, 75%)**;** ICC: Intraclass correlation coefficient, calculated for empty multilevel model; *Dichotomous variable - Median (IQR) depicts proportion of observations coded as 1.

Habit degradation strategy and implementation intentions. For the Day 7 implementation intentions, substitution was the most common strategy used (69 %), followed by inhibition (26 %). Most participants created a single valid implementation intention, linking one if-component to one then-component (see Table 5; includes examples created by participants). In the majority of implementation intentions (93%), specificity of both the if- and then- components were moderately or very specific. Regarding then-component response types, implementation intentions using substitution intended to replace behaviour, for which approximately half of the implementation intentions specified the amount of replacement to be done. Implementation intentions using inhibition in turn typically intended to enforce limits set or direct attention elsewhere. Implementation intentions operationalizing cue discontinuity in turn specified performing a new behaviour to manage the cue, which was either intended to be performed once (e.g. "*then I will remove all alcohol from my home*") or repeatedly (e.g. Cue: *"Coffee in the morning";* Then component: *"then I'm not going to use the coffee machine"*).

On Day 48, 59 participants (30 %) opted to update their implementation intention. Out of these, 33 participants created implementation intentions using the same strategy as on Day 7, while 24 participants opted to change strategy. In the remaining 2 cases, the strategy could not be determined from the formulated implementation intention.

Table 5. Descriptive statistics of habit degradation strategies and implementation intention characteristics with examples from implementation intentions created by participants (N = 194).

Variable	*N*	*n* (%)	Examples from participants' IIs
Habit degradation strategy	190		
substitution		131(69%)	*If I see sweets, then I will drink a glass of water.*
inhibition		50(26%)	*If I desire alcohol, then I try to distract myself.*
discontinuation		9(4.7%)	*If I wake up, then I'm not going to use the coffee machine.*
not applicable		4	*If I am done here, then I will do it.*
II strategy congruent with selected strategy	193	167(87%)	
missing		1	
Valid implementation intention	194	186(96%)	Valid: *If I sit down for dinner, then I won't drink beer.* Invalid: *Only if I reach my destination, smoke one.*
Number of if-components	190		
0		4(2.1%)	*Snack only at special moments.*
1		175(92%)	*If I start work in the morning…*
2		9(4.7%)	*If I am stressed or feel tired…*
3		2(1.1%)	*If I have stress (job, relationship, with kids) …*
Number of then-components	190		
1		160(84%)	*...then I will stretch for 30 minutes.*
2		24(13%)	*...I will either go to the gym or alternately walk*
3		5(2.6%)	*...I eat vegetables, fruits or nuts*
4		1(0.5%)	
Specificity of (first) if-component	186		
unspecific		12(6.5%)	*If I am with people who smoke…*
moderately specific		53(28%)	*If I get tired at home…*
very specific		121(65%)	*If I am on the sofa and I have a craving…*
not applicable		4	*I don't buy cigarettes anymore.*

Table 5 (continued 1/2).

Variable	*N*	*n* (%)	Examples from participants' IIs
Specificity of then-component	190		
unspecific		14(7.4%)	*...I think of other things.*
moderately specific		78(41%)	*...then I will move (run, yoga, stairs).*
very specific		98(52%)	*...I will go walking for 10-20min.*
Then-component response type	190		
new behaviour		7(3.7%)	*...then I will remove all alcohol from my home.*
replace behaviour		140(74%)	*...then I eat nuts.*
replace: amount	140	75(54%)	*...then I drink a cup of tea.*
setting limits		37(19%)	*...then I will stick to drinking 1 glass of wine.*
directing attention		24(13%)	*...then I think about my desired weight.*
affect regulation		6(3.2%)	*...I want to pause, take a deep breath and relax.*
self-efficacy boosting		2(1.1%)	*...then think about what I have already achieved*
self-affirming		0(0%)	
Sum of response types	190		
1		170(89%)	*...I will drink only water.*
2		20(11%)	*...I will breathe calmly and mindfully and drink something.*
Intended outcome of II	194		
avoid target behaviour		123(63%)	*If I get on the tram, then I will remain standing.*
reduce target behaviour		41(21%)	*If I work in the office, I will stand for 90 minutes.*
not applicable		30(15%)	*If I am bored, then I remember my goal.*
II worded as negation	194	11(5.7%)	*If I am bored, I will not smoke.*
Usage of word "If"	194	185(95%)	*If I am stressed, I will drink only water.*
Usage of word "then"	194	102(53%)	*If I have pain, then I do exercises to relieve it.*
Potential mismatch between cue & if-component	194	29(15%)	Cue: *Stress* II: *If I desire alcohol, I'll make myself a tea.*
Multiple IIs created	194	3(1.5%)	*If I come to the office, I put my desk up and start working standing up. If I am in the home office, I consider a different work location for the tasks to be read*

Table 5 (continued 2/2).

Variable	*N*	*n* (%)	Examples from participants' IIs
II updated on Day 48	194	59(30%)	
strategy maintained		33(17%)	Day 7: *If I am anxious, then I will look it bravely in the eye and accept it.* Day 48: *If I encounter anxiety, I will remember that it needs a lasting solution and that alcohol usually makes it worse.*
strategy changed		24(13%)	Day 7: *If I am in the office or kitchen at work then I will remind myself to only after lunch eat one portion of sweets.* Day 48: *If I see sweets at work, I'll go for a walk for a minute instead of eating sweets.*
not applicable		2(1%)	

Note. All variables displayed are derived from the qualitative analysis; II: Implementation intention; Example IIs are translated from German.

3.3.2 Time invariant predictors of Day 91 habit strength

Multiple linear regression results (see Supplementary material II section 7.3.2) indicated that trait self-regulation was the only person related factor that was associated with habit strength at the end of the study, where higher self-regulation was associated to lower habit strength at the end of the study (B = -0.62). However, this association was insignificant after adjusting p-values for multiple testing. Cue related factors, implementation intention characteristics or habit degradation strategy were not significantly associated to changes in habit strength by the end of the study.

3.3.3 Predictors of daily habit strength

Tables 6a-6b displays the results from the two multilevel models conducted. Based on the time parameters (noting that time was centred at the end of the study), we see that on average habit strength decreased over time with similar estimates in both models. Both models further indicate habit strength to have a positive carry-over effect with moderate effect size (β = 0.31 – 0.33) to the next day (i.e. lag-1 autocorrelation) and that initial habit strength is a significant positive predictor of daily habit strength with a large effect (β = 0.52 – 0.53). The proportion of variance explained in both models was high (conditional R^2 = 0.90 – 0.91) with 40-43% of variance being explained by fixed effects (Nakagawa et al., 2017; Nakagawa & Schielzeth, 2013). See supplementary file section 2.3 for further model fit indices.

In Model 1, between person differences but not within person fluctuation in stress was positively associated with daily habit strength with a relatively small effect (β = 0.14). Within

person variation in intention to change habitual behaviour the following day was negatively associated to daily habit strength with a small effect size (β = -0.01). Noteworthily, the random effect for intention is not included in Model 1. Within person fluctuation but not between person differences in cue encounter was positively associated to daily habit strength. There was tentative indication of between person differences in non-performance of habitual behaviour to be negatively associated with habit strength with a small effect size (β = -0.13), but this was not significant after adjusting p-values. Within person fluctuation in non-performance of habitual behaviour was negatively associated to daily habit strength with a small effect (β = -0.03). Within person fluctuation but not between person differences in perceived reward was negatively associated to daily habit strength. For within person variation in perceived reward, results indicate that on days when participants report perceived reward 1 point above their mean level, habit strength was on average .05 points lower, which corresponds to a small effect size (β = -0.04).

In Model 2, which additionally included degradation strategy and implementation intention enactment as predictors of daily habit strength, the previously described associations between determinants and daily habit strength were found, except between person differences in stress and within person intention (note random effect for intention included in Model 2), which were no longer significant. The effect sizes in Model 2 were of the same magnitude as in Model 1. Regarding strategy used, the model showed that inhibition and discontinuation did not differ from substitution in their effect on habit strength. Within person variation in implementation intention enactment was tentatively associated with habit strength, but this effect was not significant after adjusting p-values. In the sensitivity analysis conducted (Supplementary material II section 7.3.3, Table S2.3) results remained largely unchanged from Model 2 when additionally controlling for behavioural group effects, with findings suggesting daily habit strength to not differ by behavioural group.

3.4 Discussion

This study explored the person, cue, and behaviour-related determinants of habit degradation as well as the effects of habit degradation strategy and implementation intention characteristics on habit strength in the context of an attempt to degrade an existing habit. The most robust findings of the study suggest that on days with cue encounter daily habit strength was higher than on days without cue encounter. Also, on days with non-performance of habitual behaviour habit strength was lower than on days without non-performance. Furthermore, habit strength was lower on days with higher-than-average daily perceived reward. Non-robust study findings included higher average stress levels to be associated to higher daily habit strength, and for habit strength to be lower on the following day after higher-than-average daily intention strength. There was some indication of higher trait self-regulation to be associated to lower habit strength at the end of the study, and higher average non-performance of habitual behaviour to be associated to lower daily habit strength. Findings provide limited evidence for habit degradation to differ by strategy used. The qualitative analysis revealed a preference for substitution over other habit degradation strategies and that implementation intentions often had a common structure and content, typically linking one if-component to one response of at least moderate specificity. Implementation intention characteristics including wording,

specificity, intended outcome and response type were not associated with habit strength at the end of the study.

Table 6a. Multilevel model predicting daily habit strength by determinants only (Model 1, *n* = 188).

Parameters	Estimate (SE)	*95% CI*	*p**	β**	Random effects: *SD*
Intercept	1.37 (0.26)	0.87, 1.88	**<.001**	0.01	0.72
Time	0.26 (0.10)	0.05, 0.47	0.067	0.03	0.58
$Time^2$	-0.45 (0.17)	-0.78, -0.12	0.054	0.04	1.29
$Time^3$	0.28 (0.08)	0.13, 0.42	**0.003**	0.02	0.64
Lagged habit strength (centred at initial habit strength)	0.32 (0.02)	0.27, 0.36	**<.001**	0.33	0.21
Initial habit strength (grand mean centred)	0.68 (0.05)	0.58, 0.79	**<.001**	0.52	
Perceived stress (between)	0.26 (0.08)	0.11, 0.42	**0.009**	0.14	
Perceived stress (within)	0.01 (0.01)	0.00, 0.02	0.081	0.01	
Intention (between)	-0.09 (0.09)	-0.28, 0.09	0.33	-0.06	
Lagged intention (within)	-0.02 (0.01)	-0.03, -0.01	**0.002**	-0.01	
Cue encounter (between)	0.41 (0.21)	0.00, 0.83	0.152	0.09	
Cue encounter (within)	0.09 (0.02)	0.06, 0.13	**<.001**	0.03	0.13
Non-performance of habitual behaviour (between)	-0.65 (0.25)	-1.14, -0.16	0.057	-0.13	
Non-performance of habitual behaviour (within)	-0.11 (0.01)	-0.13, -0.08	**<.001**	-0.03	
Perceived reward (between)	0.14 (0.09)	-0.04, 0.32	0.259	0.09	
Perceived reward (within)	-0.05 (0.01)	-0.08, -0.02	**0.005**	-0.04	0.17
Residual					0.33

Note. Time (days) is scaled and centred at the end of the study (i.e. day 91); Degradation strategies are dummy coded, with substitution as the reference category; Between effect predictors are person mean variables; Within effect predictors are person mean centred variables; Model 2 includes only participants who used the same degradation strategy throughout the study; *p-value adjusted with Holm's (1979) method; **β are standardized coefficients based on a complete model re-fit with a standardized version of the data; CI: Confidence interval (calculated with Satterthwaite approximation); Non-perf: Non-performance.

Table 6b. Multilevel models predicting daily habit strength by determinants in combination with degradation strategy and II enactment (Model 2, *n* = 160).

Parameters	Estimate (SE)	*95% CI*	*p**	β**	Random effects: *SD*
Intercept	1.45 (0.29)	0.87, 2.03	**<.001**	0.01	0.70
Time	0.19 (0.12)	-0.04, 0.42	1.000	0.04	0.64
$Time^2$	-0.32 (0.18)	-0.68, 0.05	0.955	0.04	1.29
$Time^3$	0.21 (0.08)	0.05, 0.37	0.145	0.02	0.62
Lagged habit strength (centred at initial habit strength)	0.32 (0.02)	0.28, 0.36	**<.001**	0.31	0.19
Initial habit strength (grand mean centred)	0.71 (0.06)	0.60, 0.83	**<.001**	0.53	
Perceived stress (between)	0.21 (0.09)	0.03, 0.38	0.257	0.11	
Perceived stress (within)	0.01 (0.01)	-0.00, 0.02	1.00	0.01	
Intention (between)	-0.10 (0.11)	-0.32, 0.12	1.00	-0.07	
Lagged intention (within)	-0.02 (0.01)	-0.04, 0.01	1.00	-0.01	0.08
Cue encounter (between)	0.22 (0.24)	-0.24, 0.69	1.00	0.05	
Cue encounter (within)	0.10 (0.01)	0.07, 0.13	**<.001**	0.04	
Non-performance of habitual behaviour (between)	-0.40 (0.27)	-0.94, 0.14	1.00	-0.08	
Non-performance of habitual behaviour (within)	-0.10 (0.01)	-0.13, -0.07	**<.001**	-0.03	
Perceived reward (between)	0.18 (0.11)	-0.03, 0.38	0.998	0.12	
Perceived reward (within)	-0.06 (0.01)	-0.07, -0.04	**<.001**	-0.04	
Strategy: Inhibition	-0.11 (0.12)	-0.35, 0.14	1.00	-0.04	
Strategy: Discontinuation	-0.26 (0.25)	-0.77, 0.24	1.00	-0.04	
II enactment (between)	0.02 (0.22)	-0.43, 0.46	1.00	0.00	
II enactment (within)	-0.05 (0.02)	-0.09, -0.01	0.346	-0.02	0.20
Residual					0.33

Note. Time (days) is scaled and centred at the end of the study (i.e. day 91); Degradation strategies are dummy coded, with substitution as the reference category; Between effect predictors are person mean variables; Within effect predictors are person mean centred variables; Model 2 includes only participants who used the same degradation strategy throughout the study; *p-value adjusted with Holm's (1979) method; **β are standardized coefficients based on a complete model re-fit with a standardized version of the data; CI: Confidence interval (calculated with Satterthwaite approximation); II: Implementation intention; Non-perf: Non-performance.

3.4.1 Determinants of habit degradation

Findings from this study underscore the importance of day-to-day variation in cue and behaviour related determinants of habit strength when degrading a habit. Person related factors on the contrary appeared to be less robust determinants of habit strength in this context. Three key within-person associations were observed, each aligning with theory as subsequently discussed. Thereafter between person differences as determinants of habit strength are discussed.

First, we found that in the context of trying to degrade a habit cue encounters were associated with increased habit strength on the same day, which aligns with cues being a central concept for defining habit (Fleetwood, 2021) and conceptualizing habit degradation (see Figure 6). In the presence of an existing habit, a cue encounter may lead to a heightened awareness of the habit and may be accompanied by experiencing an impulse towards habitual behaviour. Our results suggest that cue encounters can pose a barrier to habit degradation, if individuals do not subsequently succeed in non-performance. In turn, cue encounter has not explicitly been investigated in habit formation studies, where cue encounters have often been controlled by instructing participants to choose a cue that specifically occurs once per day every day (Fournier, d'Arripe-Longueville, Rovere, et al., 2017; Keller et al., 2021; Kilb & Labudek, 2022; Lally et al., 2010).

Second, non-performance of habitual behaviour following a cue encounter was associated to lower habit strength on the same day. This aligns with the theorized notion of non-performance of habitual behaviour being key to habit degradation (Tobias, 2009), as also depicted in Figure 6. In habit formation, within person effects for cue-behaviour performance have correspondingly been found to be positively associated with habit strength (Keller et al., 2021; Kilb & Labudek, 2022).

Third, our results indicate that on days when people find reducing the habitual behaviour more rewarding than typically, habit strength on the same day is lower. This might suggest that perceiving non-performance as rewarding may reinforce habit degradation, akin to findings from habit formation research. Specifically, in habit formation research it has been shown that perceived reward can strengthen the impact of each repetition for gains in habit strength (Judah et al., 2018), and that positive affective attitude towards a behaviour may foster related habit formation (Han et al., 2025). Within-person variation in same-day intrinsic reward has similarly been shown to be positively associated to habit strength in habit formation (Di Maio et al., 2022).

Lastly, there was tentative indication of intention to reduce habitual behaviour to be associated to lower habit strength the following day (Table 6a, Model 1). However, this effect might not be robust. The random effect for intention was not included in Model 1 to support convergence, and the effect was no longer present in Model 2 (Table 6b) where the random effect for intention was included.

In contrast to within-person associations observed, results for more stable between person differences as predictors of habit strength were limited. These null effects should be interpreted in light of statistical power. Our planned sample size of 200, based on simulation-based recommendations for multilevel modelling (Arend & Schäfer, 2019), assumed medium-sized between-person effects. However, the observed effects were consistently of small magnitude, suggesting that the study was likely underpowered to detect between-person effects. In habit formation research between person effects of cue-behaviour performance have been found to be positively associated with habit strength (Keller et al., 2021; Kilb & Labudek, 2022). Similarly between person differences in intrinsic reward have been shown to be positively associated to habit strength in habit formation (Di Maio et al., 2022; Kilb & Labudek, 2022). As such, the present statistically non-significant findings for overall frequency of cue encounter,

non-performance of habitual behaviour and average level of perceived reward should be interpreted with caution and are likely due to insufficient power. Results were nonetheless suggestive of higher average frequency of non-performance of habitual behaviour to be associated with lower daily habit strength, which is theoretically sound.

Present findings also showed some indication for between person differences in the examined person related determinants of habit strength. First, the tentative findings of higher than-average-stress being associated with higher habit strength is aligned with previous work suggesting heightened stress to lead to a higher reliance on habit (Fournier, d'Arripe-Longueville, & Radel, 2017; W. Wood & Rünger, 2016). Second, findings suggested that higher trait self-regulation may be associated to lower habit strength at the end of the study, but this was statistically non-significant. Beyond power issues, this null finding may be linked to trait-level self-regulation being a relatively distal component of state-level self-regulation. To capture self-regulation in a manner relevant to habit degradation efforts, it could be promising to measure the usage of self-regulation strategies in daily life (Lopez et al., 2021; Milyavskaya et al., 2021).

3.4.2 Cues in the context of habit degradation

This section addresses the present study's unique insights about what type of cues tend to govern habitual behaviour. Present findings provide some of the first empirical insights into the types of cues individuals consciously associate with their existing habitual behaviours, which appears to be rather idiographic. For instance, some participants perceived cues as simply internal states without further elaboration (e.g. "*Stress*"), while others combined various contextual characteristics. The present study was unable to interpret findings through the lens of cue salience, as the cues selected by participants could not reliably be distinguished in this regard. This may reflect a broader conceptual matter: while effective cue salience may be relevant in habit formation (Gardner & Lally, 2018) it may be a less important attribute in habit degradation, as the cues of previously established habitual behaviours have acquired salience (Esber & Haselgrove, 2011). Interestingly, participants rarely defined cues based on clock time (e.g., 12 p.m.). Instead, they more commonly referenced routine or temporal contexts (e.g., lunch break). This pattern suggests that time of day may be an unlikely candidate for triggering previously established habits, possibly because it requires active monitoring (Gardner & Lally, 2018; McDaniel & Einstein, 2000). Nevertheless, previous habit formation research has shown that habit strength can increase with both time- or routine-based cue planning (Keller et al., 2021). Present findings of context stability of cues being rated relatively highly is aligned with the concept of context-consistent behavioural repetition in the presence of the cue being key to habit formation (Gardner, 2015; Gardner et al., 2024). Although context stability was not associated to habit strength in the present study, prior findings indicate positive within- and between-person associations with same-day habit strength in habit formation (Kilb & Labudek, 2022).

3.4.3 Habit degradation strategies and implementation intentions

The lack of variation in habit strength between strategies in present results may suggest that all degradation strategies are equally effective. These findings are aligned with the conceptualization presented in Figure 6 in that the common 'pathway' through which all

strategies work is non-performance of habitual behaviour. Furthermore, in congruence with this interpretation, a recent study found that substitution and inhibition both lead to the reduction of habit strength for evening device use (Hill et al., 2025). In this regard, present findings contradict the theorized notion of substitution being the only strategy to target habit opposed to habitual behaviour (Gardner et al., 2021, 2024). The lack of superiority of substitution in habit degradation may seem puzzling considering substitution's unique contribution to the formation of a new habit. While recent work has shown that during habit substitution both habit degradation and formation may be observed (Di Maio et al., 2025), these findings alone do not indicate degradation to occur as a function of the formation of a new habit. Put differently, formation of a new habit does not seem to necessitate the degradation of an existing habit as one cue may in principle be associated with more than one habitual response. As such, habit degradation may progress similarly across substitution, inhibition and cue discontinuity, while in the case of substitution habit formation may be progressing in parallel.

A further viewpoint for theoretical consideration is whether habit degradation strategies facilitate the formation of a habit of not doing (De Vries et al., 2011; Knussen & Yule, 2008; Mullan & Novoradovskaya, 2018). This could for instance imply that inhibition facilitates the formation of a new habit of non-performance. Also, it is worth noting that for sedentary behaviour inhibition, reduced availability and cue discontinuation ultimately necessitate substitution (i.e. not being sedentary requires alternative behaviour), so the relevance of each strategy also depends on the target behaviour at hand.

The lack of variation in habit strength between degradation strategies should be interpreted cautiously. Firstly, the study lacked experimental control and strategy was self-selected. Furthermore, substitution was the most used habit degradation strategy, and this preference potentially speaks on behalf of ease of use and feasibility (Milyavskaya et al., 2021). It is also possible that habit degradation strategies have differing effects on habit strength over longer time intervals than what was observed in the present study. Importantly, substitution may be more suitable for attaining long-term change (Gardner et al., 2021; Rebar et al., 2022). Additionally, cue discontinuity was used in only 9 implementation intentions created on Day 7, indicating that discontinuation related findings are driven by a minority of participants. Interpretation of strategy related results needs to also consider that findings are specific to operationalization through implementation intentions. For example, discontinuation may alternatively be operationalized through a change in the environment such as relocation (Walker et al., 2015), which could have a different effect on habit strength compared to when this is operationalized with implementation intentions. Similarly, nudging can be used to facilitate habit degradation (Rebar et al., 2022; Venema et al., 2020). All discussion taken together, further research of experimental design is needed to investigate whether, how, and with what operationalization habit degradation strategies may differently impact habit strength.

As previously noted, in this study habit degradation strategies were operationalized with implementation intentions. Overall, it can be concluded that the implementation intentions worked relatively well in degrading habit strength, without indications of decreased effectiveness for minor deviations in intended format. The fact that implementation intention characteristics were not associated with habit strength at the end of the study may in part be attributable to a lack of variability and/or ceiling effect, as implementation intentions were

generally rather similar and of good quality across participants. Although not significant, present findings were suggestive of habit strength being lower on days when the implementation intention was enacted compared to when it was not enacted (Table 6b, Model 2). This is logical as enactment facilitates non-performance of habitual behaviour (or at least reduced performance, depending on exact formulation). Moreover, this is in line with recent findings for substitution of commuting habits suggesting weekly plan enactment to be negatively associated to the old commuting habit (Di Maio et al., 2025).

3.4.4 Practical implications

Present findings may inform how interventions can be designed to degrade unwanted habits. As there was not an indication of any specific strategy to be superior, we can recommend introducing individuals to all strategies and advising them to apply a strategy according to personal preference. Substitution may be introduced as a pragmatic starting point, and the relevance of non-performance of habitual behaviour can be emphasized. Individuals may also be advised to pursue non-performance of habitual behaviour in a manner that feels rewarding to them. Furthermore, manipulating the reward value of non-performance of habitual behaviour may be a viable approach to boost habit degradation interventions. Based on the overall relatively high quality of implementation intentions seen in the present study, it would seem sufficient to provide such instructions in written format, at least when individuals are autonomously motivated towards behaviour change.

3.4.5 Strengths and limitations

This work brings novel contributions to habit research. It is the first to compare strategies of habit degradation, and among the first (Di Maio et al., 2025) to look into within and between person predictors of habit strength in the context of habit degradation. The study bears several methodological strengths that enabled comprehensive assessment of real-world habit degradation, including usage of experience sampling methods, qualitative analysis of implementation intentions that facilitated gaining practical insights about participants' tendencies in this regard, and providing results that span across four behavioural domains.

Given the exploratory nature of the study, results should be interpreted as hypothesis-generating. While adjustments for multiple comparisons were applied, the number of predictors raises the risk of false positives, warranting replication in future studies. Study limitations further include reliance on self-report measurements, which is of particular concern for habit strength, as habit operates outside of awareness (Gardner & Tang, 2014; Hagger et al., 2015). Nonetheless, habit strength was assessed by perceived automaticity which is subject to reflection (Di Maio et al., 2025; Gardner & Lally, 2023; Orbell & Verplanken, 2015). Furthermore, present findings provide some support of construct validity for measuring habit strength with the SRBAI, as cue encounter and non-performance of habitual behaviour are conceptually key constructs related to habit strength (see Figure 6), and these were consistently associated with habit strength at the within-person level.

The study showcased examples of person, cue, and behaviour related determinants of habit degradation, and is not comprehensive in these regards. For example, person related factors such as identity (Zhu et al., 2025) and behaviour related factors such as habitual (non-)performance related regret (Di Maio et al., 2025) may be additional relevant constructs. Future

studies should also consider reward value of an alternative behaviour, opposed to in relation to non-performance as done in the present study. For example, in the context of substitution, within person variation in the reward value of the substitute behaviour has been shown to be positively associated with habit strength for the substitute behaviour (Di Maio et al., 2025).

3.4.6 Conclusions

This study contributed towards refining habit theory by exploring a range of determinants of habit degradation. Using intensive longitudinal data, present findings suggest day-to-day variation in non-performance of habitual behaviour and associated perceived reward to be relevant determinants of habit degradation, while day-to-day variation in cue encounter to be associated with higher habit strength. These were the most robust findings in this study. There was no evidence that some habit degradation strategies are more effective than others, but substitution seems to be preferred by people over other strategies. Future research leveraging experimental designs is needed to replicate and extend the accumulating evidence base of the determinants and strategies of habit degradation.

Data availability statement: R-scripts and data are available at: https://osf.io/b69gp/.

4. Manuscript III – Degrading unhealthy snacking habits in the real world: A randomised controlled intensive longitudinal study

This manuscript is under peer review. The article preprint is available online: Edgren, R., Baretta, D., & Inauen, J. (2025). Degrading unhealthy snacking habits in the real world: A randomised controlled intensive longitudinal study. https://doi.org/10.31219/osf.io/z5gd7_v2.

Supplementary material III contains additional information for this manuscript.

Author contributions

Robert Edgren: Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization, Project administration, Data curation. **Dario Baretta:** Methodology, Formal analysis, Visualization, Writing – review and editing, Validation. **Jennifer Inauen:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review and editing.

Abstract

Habits are a key determinant of sustained health behaviour. However, little is known about how to degrade unhealthy habits in daily life. This preregistered single-blind randomised controlled intensive-longitudinal trial tested the efficacy of habit degradation strategies (substitution, inhibition, reduced accessibility) and reward in degrading an unhealthy snacking habit in daily life using a 3×2 factorial (plus control group) design. 313 participants (mean age 32 years) were randomised via smartphone app to complete 13 weeks of daily self-report assessments. From 13,922 habit strength (Self-Report Behavioural Automaticity Index) observations, within-person time series were modelled using asymptotic functions and generalised additive models to extract indicators of habit change. Habit strength declined over time across groups, with steeper reductions during the first week of the intervention phase. Analysis of variance indicated the rate of change during week 1 to be significantly greater in intervention groups compared to control. Analysis of covariance and logistic regression indicated no differences for strategy or reward condition in magnitude of change, likelihood of reaching asymptote, or time to asymptote, but there was not credible evidence for these null findings. Results suggest using habit degradation strategies may accelerate early reductions in habit strength. Findings are discussed considering the opportunities and challenges of experimental intensive longitudinal designs in real-world settings.

4.1 Introduction

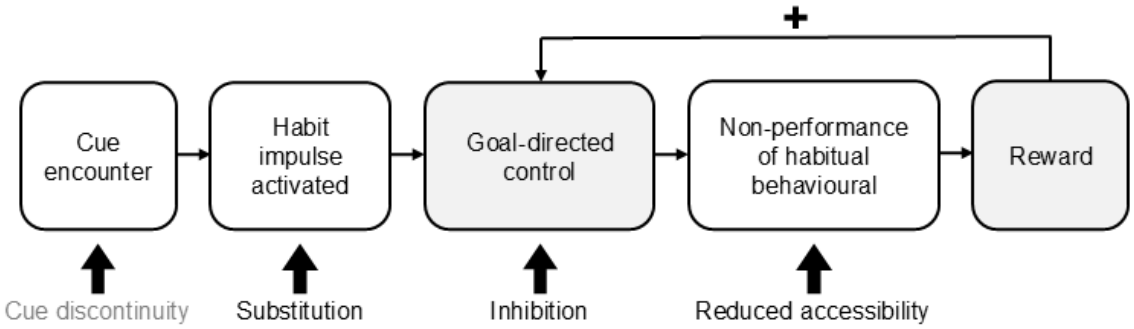
Habits are conceptualized as cue-behaviour associations learned through repetition and characterised by automaticity (Fleetwood, 2021; Moors & De Houwer, 2006). Importantly, habit is a determinant of behaviour, whereby encountering a cue (e.g. seeing biscuit jar on kitchen counter in the afternoon) stimulates an impulse towards the associated habitual behaviour (e.g. eating biscuit) (Gardner et al., 2024). While it is a topic of discussion whether reward is central to defining habit (Gardner & Lally, 2023; Labrecque & Wood, 2015; Phillips & Mullan, 2023), it is generally agreed that perceiving a behaviour as rewarding may promote habit formation (Gardner & Lally, 2018; W. Wood & Neal, 2007; W. Wood & Rünger, 2016), which has been supported empirically in daily life (Di Maio et al., 2022, 2025; Judah et al., 2018). Experimental psychology has shown that once a habit is formed, it is performed even in the absence of reward. This has been referred to as "outcome insensitivity" and is considered a defining feature of habitual behaviour – that is, the continuation of behaviour despite no longer being rewarding (Dickinson et al., 1985) (e.g. eating unpleasant stale biscuit). Whereas these outcome devaluation paradigms have demonstrated habitual behaviour in rats, a strict dichotomy between goal-directed and habitual behaviour in humans seems less likely based on the existing evidence (De Wit et al., 2018). In humans, habit seems to be influenced by an interplay between habitual and goal-oriented processes (De Wit et al., 2018; Gardner et al., 2024; Watson et al., 2022), with evidence supporting this notion of an interaction between habitual and goal-oriented processes for complex habitual behaviours in daily life (Saunders & More, 2025). Taken together, laboratory-based findings may not translate to daily life because they lack real-world complexity. However, daily life studies with high ecological validity are often observational. Embedding experimental manipulations within intensive-longitudinal daily-life designs can therefore be an insightful extension to prior work.

Once established, habits may be resistant to change (Gardner et al., 2021; Lally & Gardner, 2013), which in the case of habits with negative consequences such as those related to diet (Riet et al., 2011; Verhoeven et al., 2012) can be detrimental to health. Therefore, a line of research has focused on strategies to reduce or degrade a habit (Edgren & Inauen, 2025a; Gardner et al., 2021, 2024). In reference to a purposeful attempt to 'break' a habit, we use the term habit degradation. Breaking (or disrupting) a habit suggests that the habit no longer elicits an impulse to act at the occurrence of a cue. While this could happen, the term habit degradation describes the different grades of habit reductions contributing towards breaking a habit. Previous work has also referred to habit decay, which we reserve to describe a passive process of habit reduction when the habitual behaviour is not performed (Tobias, 2009). In health psychology habit degradation is theorized to occur through habit substitution, wherein a new behavioural response is repeated at cue-encounters (e.g. replacing biscuit with drinking water) which alters the underlying habit and associated habit impulse (Gardner et al., 2021, 2024) (Figure 8). Other strategies, namely cue discontinuity (avoiding cue, e.g. avoid entering kitchen in afternoon), inhibition (wilfully stopping performance, e.g. by motivational self-talk), and reduced accessibility (limiting availability of target behaviour, e.g. getting rid of biscuits from home) on the contrary are theorized to not directly displace the underlying habit (Gardner et al., 2021, 2024) because these do not intervene on and change the underlying habit and habit impulse (Figure 8). To date, only one study (Edgren & Inauen, 2025a) has investigated whether

degradation strategies differ in their effectiveness. This study did not find differences between strategies, which may have been due to a lack of experimental control (Edgren & Inauen, 2025a). Thus, to advance habit theory and potential applications, it is of utmost importance to empirically establish the effectiveness of degradation strategies as they are applied in daily life.

As reward is known to play a role in habit formation, it is feasible for reward to also be relevant in habit degradation. Indeed experimental research has demonstrated that combining performance feedback and monetary incentives (i.e. reward) can restore goal-directed control and degrade habits (Figure 8), where degradation was operationalized as disrupting outcome insensitivity (Ceceli et al., 2020). This experimental research however lacks ecological validity in terms of complexity inherent to daily life. Whether similar effects generalize to real-world habit degradation thus remains an open empirical question. Importantly, investigating the role of reward in habit degradation in daily life serves to enhance our understanding of the mechanisms of habit as it occurs in naturalistic settings.

Figure 8. Diagram of how strategies target and how reward may facilitate habit degradation mapped on to the habit activation process.



Note. Non-performance of habitual behaviour can be pursued using habit degradation strategies (visualised with thick arrows). They intervene on various parts of the habit degradation process: cue discontinuity (Walker et al., 2015) targets the cue encounter (not investigated in present study), substitution targets the cue-behaviour association that underlies and generates the habit impulse, inhibition (Quinn et al., 2010) entails wilfully stopping performance of habitual behaviour, and reduced accessibility entails stopping performance of habitual behaviour through limiting availability of the target behaviour (Gardner et al., 2024). If non-performance is rewarded (i.e. positive outcome value), the disposition towards goal-directed control may be reinforced. The figure builds upon previous theoretical work (Edgren & Inauen, 2025a; Gardner et al., 2024; Gardner & Lally, 2018) and empirical findings (Ceceli et al., 2020).

4.1.1 Studying habit degradation in daily life

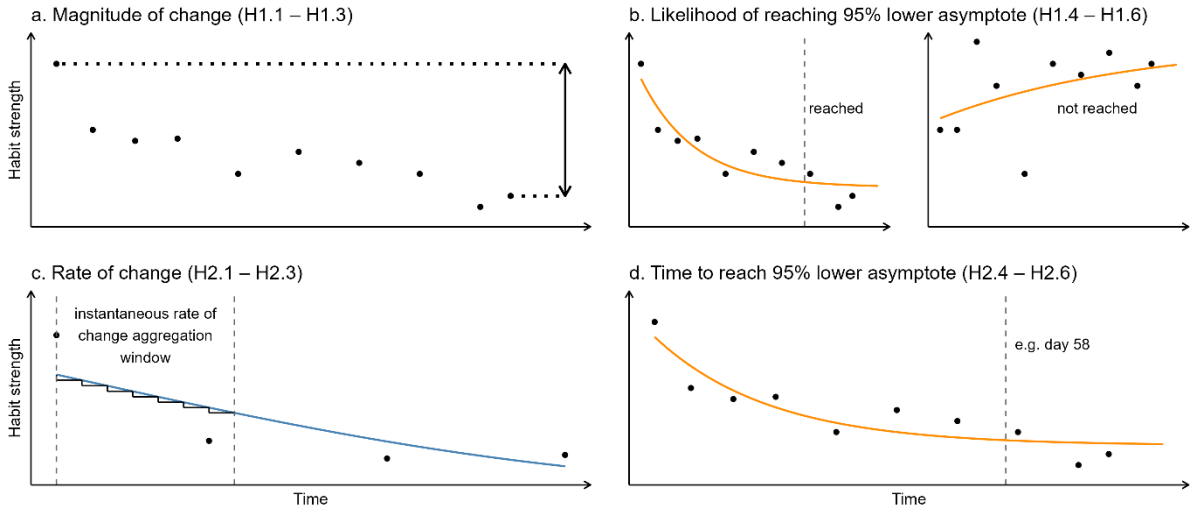
An important challenge in habit research lies in translating the experimental control typical of laboratory-based psychology into ecologically valid, daily-life settings. Experimental paradigms enable testing isolated hypotheses such as outcome insensitivity with instrumental training, devaluation and test phases (Thrailkill et al., 2025). In contrast, habit research grounded in health psychology often emphasizes ecological validity. Bridging these approaches—by embedding theoretically grounded manipulations, such as habit degradation strategies and reward contingencies, within naturalistic, intensive longitudinal designs—offers

a promising and novel route to test the mechanisms of habit degradation as it unfolds in complex everyday contexts.

Central to this effort is defining outcomes that meaningfully capture change in habit over time. Guidelines for habit tracking studies in daily life note the speed and level at which habit peaks (in the case of habit formation) to be informative outcomes (Gardner et al., 2022). However, there are no standards for outcome operationalization, and methodological challenges hamper efforts to harmonize the quantification of change, as subsequently outlined. Previous research has modelled habit strength change over time to understand the progression of both formation (Baretta et al., 2024; Keller et al., 2021; Lally et al., 2010) and degradation (Edgren et al., 2024). This prior work shows that change is often non-linear, heterogenous and rarely conforms neatly to a single functional form across participants (Baretta et al., 2024; Edgren et al., 2024; Lally et al., 2010). For instance, an asymptotic model enables meaningful interpretation of time for stabilization to occur, but may be an inaccurate description of most of the observed trend in the time series (Edgren et al., 2024; Lally et al., 2010). This variability underscores the need for additional outcomes that can be extracted consistently across different trajectory types. Simultaneously, there is added value in investigating habit degradation from multiple perspectives, as this may facilitate gaining a more nuanced understanding to the dynamics of change.

Capturing both the extent and dynamics of habit change in daily life requires analytic approaches that can accommodate heterogeneous, idiosyncratic trajectories. Within-person modelling offers a flexible alternative to group-level analyses (Edgren et al., 2024) and has been used to describe change patterns (Baretta et al., 2024; Edgren et al., 2024) and estimate time for asymptotic stabilization to occur (Edgren et al., 2024; Keller et al., 2021; Lally et al., 2010). Within this context, to capture change from complementary perspectives it is suitable to account for the extent of change (Figure 9 a), whether stabilization occurs (Figure 9 b), and how long stabilization takes (Figure 9 d). Importantly, in acknowledgement of the importance of outcome timing in longitudinal data (Berli et al., 2021), the relevance of rate of change when investigating temporal processes (George & Jones, 2000), and previous research on habit degradation showing decline to be steepest during the first weeks (Edgren et al., 2024), the rate of change – or speed (Figure 9 c) during this initial stage is of particular interest. In summary, by leveraging multiple within-person modelling techniques several meaningful indicators of change in habit strength can be extracted, which in turn facilitates comprehensive evaluation of the habit degradation process.

Figure 9. Within-person outcomes for habit strength degradation.



Note. Conceptual illustration of four outcomes that can be extracted from within-person habit strength time series data. Plot titles indicate (in brackets) the corresponding hypotheses shown in Table 7. **a. Magnitude of change** reflects the reduction in habit strength across a time frame. **b. Likelihood of reaching 95% of the lower asymptote** indicates whether habit appears to stabilize (Lally et al., 2010) at a reduced strength, which may be a marker of habit degradation approaching completion (Edgren et al., 2024). In the right plot the lower asymptote is not being reached because habit strength is increasing over time; **c. Rate of change** captures how quickly habit strength changes, with negative values indicating a decrease. The average rate of change for a given time window (here 7 time units) can be estimated by averaging the corresponding instantaneous rate of change values. **d. Time to reach 95% of the lower asymptote** estimates how long it takes for habit strength to stabilize at a reduced strength.

4.1.2 The present study

Engagement in health-risk related behaviours such as poor diet (Muller et al., 2016) may be influenced by underlying habits, as has been shown to be the case with unhealthy snacking (Verhoeven et al., 2012). Accordingly, this study investigates whether three habit degradation strategies (inhibition, substitution and reduced accessibility) and reward facilitate habit degradation related to unhealthy snacking using a 3x2 factorial plus control group intensive longitudinal design. This will be investigated using the four outcomes outlined previously (Figure 9). In line with theoretical accounts, we hypothesized that all degradation strategies outperform control in facilitating habit degradation, with substitution expected to be most effective, and for reward to facilitate habit degradation. See overview of hypotheses in Table 7.

Table 7. Preregistered research questions and hypotheses.

RQ 1: Does habit degradation strategy and receiving reward facilitate achieving lower habit strength (i.e. magnitude of change) after 12 weeks, and reaching the 95% lower asymptote?	Outcome	Comparison
H1.1: Habit strength is lower after 12 weeks among participants using a habit degradation strategy (substitution, inhibition or reduced accessibility) compared to the control group.	Magnitude of change	intervention vs. control
H1.2: There is a group difference in habit strength after 12 weeks between the habit degradation strategy groups. Substitution is hypothesized to lead to lower habit strength after 12 weeks compared to inhibition and reduced accessibility.	Magnitude of change	substitution vs. inhibition vs. reduced accessibility
H1.3: Among participants in any habit degradation strategy group receiving reward, habit strength is lower after 12 weeks compared to participants in any habit degradation strategy group not receiving reward.	Magnitude of change	reward vs. no reward
H1.4: There is a higher likelihood of participants using a habit degradation strategy to reach the 95% lower asymptote within the time series compared to the control group.	95% asymptote (reached vs. not reached)	intervention vs. control
H1.5: There is a group difference in the likelihood of participants to reach the 95% asymptote within the time series between the habit degradation strategy groups. There is higher likelihood of participants in the substitution group to reach the 95% lower asymptote within the time series compared to participants in the inhibition and reduced accessibility groups.	95% asymptote (reached vs. not reached)	substitution vs. inhibition vs. reduced accessibility
H1.6: Among participants in any habit degradation strategy group receiving reward, there is a higher likelihood of participants reaching the 95% lower asymptote within the time series compared to participants in any habit degradation strategy group not receiving reward.	95% asymptote (reached vs. not reached)	reward vs. no reward

Table 7 (continued). Preregistered research questions and hypotheses.

RQ 2: Does habit degradation strategy and receiving reward facilitate habit strength to decrease at a faster rate during the first two weeks of degrading a habit, and to reach the 95% lower asymptote in a shorter period of time?	Outcome	Comparison
H2.1: Habit strength decreases at a faster rate during the first two weeks among participants using a habit degradation strategy (substitution, inhibition or reduced accessibility) compared to the control group.	Rate of change	intervention vs. control
H2.2: There is a group difference in the rate of change of habit strength during the first two weeks between the habit degradation strategy groups. The rate of change is hypothesized to be faster among the substitution group compared to inhibition and reduced accessibility groups.	Rate of change	substitution vs. inhibition vs. reduced accessibility
H2.3: Among participants in any habit degradation strategy group receiving reward, habit strength decreases at a faster rate during the first two weeks compared to participants in any habit degradation strategy group not receiving reward.	Rate of change	reward vs. no reward
H2.4: The time for 95% of the lower asymptote to be reached is shorter among participants using a habit degradation strategy compared to the control group .	Days to reach 95% asymptote	intervention vs. control
H2.5: There is a group difference in time for habit degradation to occur between the habit degradation strategy groups. The time needed to reach 95% of the lower asymptote is hypothesized to be shorter among the substitution group compared to inhibition and reduced accessibility groups.	Days to reach 95% asymptote	substitution vs. inhibition vs. reduced accessibility
H2.6: Among participants in any habit degradation strategy group receiving reward, time needed to reach 95% of the lower asymptote is shorter compared to participants in any habit degradation strategy group not receiving reward.	Days to reach 95% asymptote	reward vs. no reward

Note: RQ: research question; H: hypothesis

4.2 Methods

This single-blind randomised controlled trial with intensive-longitudinal assessment employed a 3 (strategy: substitution, inhibition, reduced accessibility) × 2 (reward: yes/no) between-person factorial design, plus a control group. The study was preregistered (https://osf.io/mnfku/). Recruitment started in June 2024 and data collection was completed in December 2024. Reporting adheres to the CREMAS (Liao et al., 2016) and CONSORT (Hopewell et al., 2025) reporting guidelines. The ethics committee of the authors' faculty granted ethical approval for the study.

4.2.1 Population and sample

Eligibility criteria for participation included providing informed consent, being at least 18 years of age, fluent German language skills, owning an iOS or Android smartphone with internet access, not having diabetes or a diagnosed eating disorder, reporting having the tendency to at

least occasionally eat unhealthy snacks, an existing habit for unhealthy snacking at home (Self-Report Behavioural Automaticity Index (Gardner et al., 2012; Verplanken & Orbell, 2003) (SRBAI) score above scale midpoint), and a willingness to reduce unhealthy snacking at home and engage with the study app daily for 13 weeks.

An a priori power analysis using ANCOVA (3x2 factorial) indicated that 214 participants would provide 80% power to detect a 0.5-point difference in habit strength, which we defined as the smallest effect size of interest (SESOI) for magnitude of change when the SRBAI scale ranges 0–4. Accounting for a 70% retention rate based on prior research (Edgren et al., 2024), 307 participants were aimed to be recruited (see Supplementary material III section 8.1.1 for further details).

The magnitude of change SESOI and SESOI for the remaining three outcomes (determined post-hoc) were used in power determination analysis (Giner-Sorolla et al., 2024; Lakens & Caldwell, 2021) to strengthen the evidence of null findings, as subsequently described. For the outcome likelihood of reaching 95% of lower asymptote, as a previous observational study on habit degradation found 22% of the sample to reach this threshold (Edgren et al., 2024), the odds ratio range of 0.80 to 1.25 was defined as the SESOI. As the outcome rate of change was used in a novel context, the SESOI was determined based on the magnitude of change SESOI (±0.5 change in SRBAI), and the previous finding that habit degrades in a decelerating fashion with stabilization typically taking less than two weeks (Edgren et al., 2024). Specifically, the SESOI for average rate of change was defined as ±0.034, which is approximately the average rate of change needed to achieve 95% of the magnitude of change SESOI within the first two weeks of the intervention ([0.5*0.95] / 14). Lastly, the SESOI for days needed to reach 95% of the lower asymptote as defined as the smallest detectable difference, i.e. ±1 day. For each SESOI simulation-based power determination analysis were conducted accounting for the study's experimental design and condition specific sample sizes and standard deviations. Power determination analyses indicate the power of the study design to detect a true effect equivalent to the SESOI, which in turn informs how to interpret a null finding, where in the case of high power (≥ 80%), a null is informative and otherwise (power < 80%) inconclusive. These power detection analyses (see Supplementary Table S3.5 in section 8.2.3 for further details) indicated that the study was fully powered to detect the magnitude of change SESOI, partially powered to detect the rate of change SESOI, and underpowered to detect the SESOI for likelihood and time to reach 95% of the asymptote (see Supplementary Table S3.5). In light of being the first study to use the outcomes likelihood to reach asymptote and rate of change in habit research, the present study will provide helpful evidence for planning subsequent studies, despite being partially underpowered for these particular analyses.

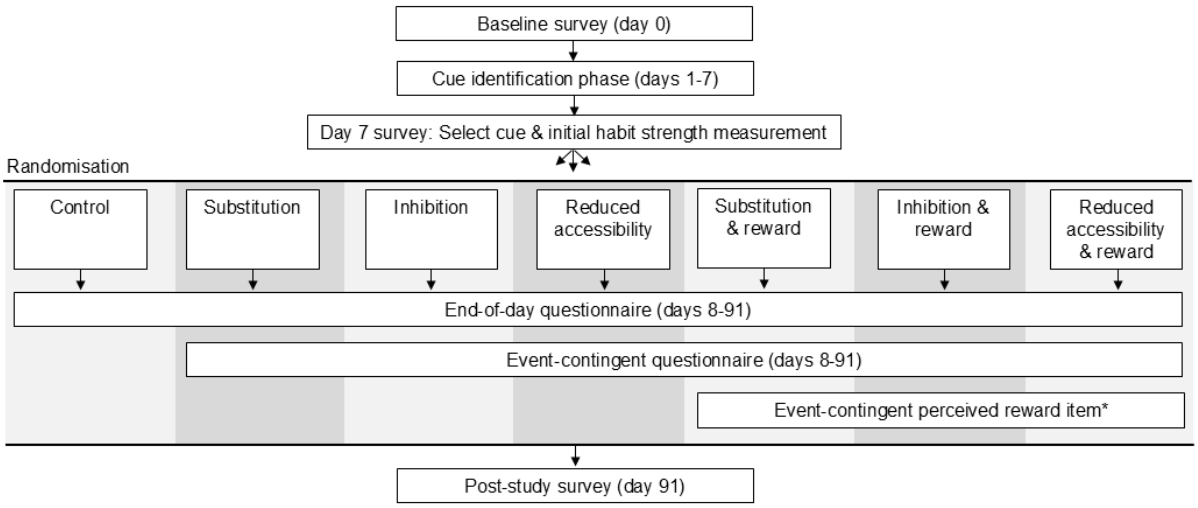
4.2.2 Procedure

Recruitment was conducted with social media advertisements stating unhealthy snacking habit degradation as the topic of the study. All procedures (Figure 10) were conducted remotely via the study app. The study consisted of one sampling period that lasted for 91 days (including 26 weekend days) that combined interval- and event-contingent responding. All repeated measures were displayed in a fixed order. Participants received a notification to complete the end-of-day questionnaire in the evening at a self-selected time (19:00 or later). Participants were instructed

to select a time that allowed them to answer the questionnaire just before bedtime. Once opened, there were no additional time restrictions for completing the questionnaire. Participants received a reminder at 08:00 AM to complete the end-of-day questionnaire for the previous day if a response had not been provided.

Participants were randomised in the study app using a restricted randomisation approach into one of seven groups (see Figure 10) on Day 7, following cue selection and initial habit strength measurement. Researchers remained blind to group allocation during intervention delivery but not during analysis, because group allocation needed to be known to assess intervention fidelity. Participants in experimental conditions were unaware of specific group allocations, while control group participants were informed of their non-intervention status. During the intervention phase (days 8-91), intervention group participants attempted to degrade their unhealthy snacking habit according to their implementation intention (Edgren et al., 2024; Gollwitzer, 1993) (see Experimental manipulation section below). All participants (except control group) were instructed to independently initiate responding to the event-contingent questionnaire upon encountering their cue in daily life (i.e. no prompting). The event-contingent questionnaire included three items that assessed cue encounter and subsequent behaviour as follows: "I have now encountered my selected situation" (answer options: no, yes), "How many unhealthy snack portions did you eat?" (answer options: none – 10 or more), and "I successfully implemented my plan" (answer options: no, yes). The event-contingent questionnaire was estimated to take under 30 seconds to complete.

Figure 10. Overview of intensive longitudinal study design, group allocation, and data collection schedule.



Note. Participants completed a baseline survey (Day 0), followed by a 7-day cue identification phase. On Day 7, participants selected a habitual snacking related cue and were randomised into one of seven groups (3×2 factorial plus control). End-of-day questionnaires were completed throughout the study (Days 1–91). Participants in experimental groups also completed event-contingent questionnaires (Days 8–91), and those in reward conditions received reward feedback via pop-up messages and accumulated points in the app. *The perceived reward item was administered to participants in the reward condition on 12 pre-specified occasions following reward delivery.

If participants wished to terminate participation, the study app included an icon allowing them to do so. Participants received debriefing after completing the post-study survey or upon early termination. Following completion or termination, compliance was calculated, and participants were reimbursed up to 120 CHF via bank transfer. Participants could access compliance information, including the number of end-of-day questionnaires completed during the ongoing week and overall compliance in responding to the end-of-day questionnaires within the study app (see Supplementary material III section 8.1.3 for further details on randomisation, reimbursement and interval-contingent data collection).

4.2.3 Experimental manipulation

Experimental manipulation of habit degradation strategy and control took place on day 7 (Figure 10). All intervention groups received instructions to formulate implementation intentions (Edgren et al., 2024; Gollwitzer, 1993), which varied according to group assignment. See Supplementary material III section 8.1.4 for the specific guidelines. **Substitution** strategy group participants were instructed to formulate an implementation intention aimed at replacing unhealthy snacking with an alternative behaviour, such as a healthy snack or physical activity. **Inhibition** strategy group participants formulated implementation intentions designed to wilfully inhibit unhealthy snacking, for example, through motivating self-talk. **Reduced availability** strategy group participants were instructed to formulate implementation intentions to remove the availability of unhealthy snacks when encountering their cue. Implementation intentions were recorded as an open-ended response. **Control group** participants were instructed not to degrade their unhealthy snacking habit, did not formulate an implementation intention, and only answered the end-of-day questionnaires for the remainder of the study.

Experimental manipulation of the **reward condition** took place from day 8 onwards, which was implemented based on event-contingent questionnaire responses (Figure 10). Reward was delivered based on event-contingent questionnaire responses as follows. Participants in a reward condition received a reward message after recording no snacking in response to a cue encounter. The reward message was displayed in a pop-up screen alongside an animated trophy graphic. Each day of the intervention phase had a unique reward message, which was common to all participants. The reward messages were developed based on a cross-sectional pilot study to ensure their reward value (see Supplementary material III section 8.1.2). Additionally, participants gained one in-app point for each recorded cue encounter where no unhealthy snacks were consumed. Participants were assigned an accomplishment tier based on accumulated points (bronze, silver, gold and diamond). See Supplementary Figure S3.1 in section 8.1.5 for app screenshots. Intervention fidelity was assessed for strategy and reward to determine adherence to group specific instructions, along with a manipulation check of reward based on self-reported perceived reward (see Supplementary material III section 8.1.6 for details).

4.2.4 Outcome measures

The outcome variable habit strength was measured using the validated 4-item SRBAI (Gardner et al., 2012; Verplanken & Orbell, 2003) in the end-of-day questionnaire from Day 7 to Day 91, with items scored on a 5-point Likert scale from 0 to 4. Items referenced the participant's self-selected cue, for example "*Eating unhealthy snacks when my cue "afternoon coffee break" occurs is something that I do without thinking about it*". The SRBAI composite score was

calculated with the mean of the items per participant per day. An SRBAI observation was considered valid if it was provided between 19:00 PM and 10:30 AM the following morning. Responses provided between 00:00 AM and 10:30 AM were recoded to refer to the previous day. Responses provided between 10:30 AM and 19:00 PM were excluded. The SRBAI displayed excellent between person reliability (R_{kRn} = 0.995) and satisfactory within-person reliability (R_{cn} = 0.681) in the present data (Cranford et al., 2006; Shrout & Lane, 2011). In naturalistic settings habit strength is commonly assessed based on perceived automaticity using the SRBAI (Gardner et al., 2012). While critics argue self-report is insufficient to measure the nonconscious process of habit (Gardner & Tang, 2014; Hagger et al., 2015; Sniehotta & Presseau, 2012), it has been shown that individuals can reflect on their habits (Orbell & Verplanken, 2010) and that perceived automaticity is distinct from cue-behaviour performance (Edgren et al., 2024; Edgren & Inauen, 2025a).

The outcome measures used to address the primary research questions (Table 7), magnitude of change (Figure 9 a), likelihood of reaching 95% asymptote (Figure 9 b), rate of change (Figure 9 c), and time to reach 95% asymptote (Figure 9 d) were extracted from within-person habit strength time series as subsequently described. Aside from magnitude of change, all outcomes entailed first estimating within-person models for habit strength time series with two approaches: using an asymptotic function (for likelihood and time to reach asymptote) and with generalised additive models (Hastie & Tibshirani, 1986) (GAMs; to estimate rate of change). With both within-person modelling approaches the outcome variable was daily SRBAI score, and the predictor variable was time in days. Time was centred at the first habit strength observation (day 7) such that time varied from 0 to 84.

Magnitude of change was addressed by extracting the observed initial habit strength (day 7), average habit strength from the last week (days 85-91), and the last recorded habit strength observation (if no observations were available for the last week). Habit strength from the last week was averaged to account for potential variance occurring during this time. In analyses, magnitude of change was addressed by predicting final habit strength while controlling for initial habit strength.

Asymptote related outcomes were computed based on asymptotic model parameter estimates (response at time 0 and asymptote) and model predicted values (Edgren et al., 2024; Keller et al., 2021; Lally et al., 2010) to identify if and when 95% of the lower asymptote was reached. To address **likelihood of reaching 95% of the lower asymptote**, a dummy-coded variable was created to indicate whether 95% of the asymptote had been reached within the time series. Cases where the asymptotic model was deemed non-valid were scored as 0. The criteria for deeming within-person asymptotic models valid were defined a priori, based on procedures developed in a previous study (Edgren et al., 2024). Asymptotic models were deemed valid if model estimates approached a lower asymptote (indicating a decreasing trend), the model RMSE value was ≤0.33 (indicating model accuracy), and the time series included missing gaps of observations no longer than 21 days in length (indicating sufficient data). For models deemed valid, **time to reach 95% of the lower asymptote** was calculated with the parameter estimates and model predicted values. This procedure was originally used to describe the time needed for habit formation to occur (Keller et al., 2021; Lally et al., 2010) and has subsequently been extended to habit degradation (Edgren et al., 2024).

Rate of change was computed by first fitting GAMs, which have been previously used to model habit formation in a non-linear and flexible manner (Baretta et al., 2024). For estimating within-person GAMs, the number of knots was set (post hoc) to dynamically vary based on the number of SRBAI observations present in the time series. For ≤ 10 observations, ≤ 20 observations, and > 20 observations 5, 10, and 15 knots were used, respectively. Time series were determined to have sufficient data (post-hoc criteria) for estimating GAMs if at least one observation was recorded during the first week, second week, and after the second week. Post hoc decision making was needed for estimating GAMs to ensure accurate model fit and to avoid overfitting. Subsequently, rate of change was computed with the first derivative corresponding to each time point, which corresponds to the instantaneous linear rate of change (Baretta et al., 2025; Simpson, 2018). The average instantaneous rate of change was then calculated for weeks 1 and 2 of the intervention phase (Figure 9 c).

4.2.5 Covariates

At baseline after providing informed consent, participants' demographics including age (in years), gender (multiple choice), self-reported weight (in kg) and height (in cm), and desirable responding (Winkler et al., 2006) were assessed. On day 7, intention strength to change unhealthy snacking behaviour over the subsequent 12 weeks was measured with two Likert-scale items (composite score calculated with the mean of items). Body mass index scores (kg / m^2) that were computed and scores that were three standard deviations (*SD*) above the mean were replaced with the value corresponding to three *SD* above the mean. For description of event-contingent data processing see Supplementary material III section 8.1.7. Harms were not assessed in this study.

4.2.6 Data analysis

Analyses for the primary research questions are displayed in Table 8. As multiple primary outcomes were tested, multiplicity adjustment was conducted with statistically significant results to control for false positives (Hussein et al., 2025) using the sequentially rejective Bonferroni method (Holm, 1979). For adjustment the family of tests was determined based on the number of tests conducted for each outcome. Here the logic is that hypotheses concerning a particular outcome stem from a common underlying null hypothesis (Curran-Everett, 2000; Matsunaga, 2007), specifically *strategies and reward do not impact X in habit degradation,* where *X* denotes a specific outcome. Equivalence tests were conducted for null findings using the SESOI defined previously for each outcome (Lakens et al., 2018). Missingness patterns in each outcome of interest in relation to predictors (i.e. intervention group) and covariates was investigated with logistic regression. In most cases, there were no significant predictors of missing outcome variables (consistent with missing completely at random). In two instances (missing analyses corresponding to H1.2-.3 and H2.2-.3 analyses) missing outcome was associated with intention strength. These missingness patterns were handled by running sensitivity analysis including intention strength as a covariate. Missing outcome values were not imputed, as these were intentionally missing due not meeting set criteria (see above section Outcome measures). For steps taken to assure assumptions were met for the main analyses (e.g. normality of residuals, homogeneity of variances and homogeneity of regression slopes) see Supplementary material section 8.1.8. All analyses were conducted in R version 4.3.3 (R Core Team, 2021).

Table 8. Analysis plan to address preregistered hypotheses.

Hypothesis	Analysis	Outcome	Predictors (Covariates)	Sensitivity analysis
H1.1	ANCOVA	Final SRBAI (last week average; if missing, last observation carried forward)	intervention vs. control (day 7 SRBAI)	- 1. Excluding participants with no SRBAI observations during last week - 2. Covariates added: day 7 intention strength, BMI, and desirable responding - 1. & 2. combined - 1. & reassigned actual group and excluding blended strategy use
H1.2–.3	ANCOVA	Final SRBAI (last week average; if missing, last observation carried forward)	strategy*reward (day 7 SRBAI)	- 1. Excluding participants with no SRBAI observations during last week - 2. Covariates added: day 7 intention strength, BMI, and desirable responding - 1. & 2. Combined - Reassigned actual strategy group - 1. & reassigned actual strategy group - 1. & reassigned actual group & excluding blended strategy use
H1.4	Logistic regression	Binary indicator of reaching 95% lower asymptote (1) or not (0)	intervention vs. control (day 7 SRBAI)	
H1.5-.6	Logistic regression	Binary indicator of reaching 95% lower asymptote (1) or not (0)	strategy*reward (day 7 SRBAI)	
H2.1	ANOVA	Aggregated rate of change for week 1 and 2	intervention vs. control	- Robust ANOVA - Reassigned actual group & excluding blended strategy use
H2.2-.3	ANOVA	Aggregated rate of change for week 1 and 2	strategy*reward	- Robust regression - Reassigned actual group & excluding blended strategy use - Intention strength covariate added**
H2.4	ANCOVA	Time (days) needed to reach 95% of lower asymptote (log-transformed)	intervention vs. control (day 7 SRBAI)	
H2.5-.6	ANCOVA	Time (days) needed to reach 95% of lower asymptote (log-transformed)	strategy*reward (day 7 SRBAI)	

Note. Intervention vs. control indicates inclusion of one categorical variable with 2 levels where intervention refers to all intervention groups except control; Strategy*reward indicates inclusion of main effect and interaction for strategy (substitution, inhibition, reduced accessibility) and reward (no reward, reward). All analyses were conducted as two-sided tests. **Post-hoc inclusion based on identified missingness pattern; ANCOVA: Analysis of covariance; ANOVA: Analysis of variance; BMI: Body Mass Index; SRBAI: Self-Report Behavioural Automaticity Index.

4.3 Results

313 participants reached day 7 of the study, provided an initial habit strength score and were randomly assigned to an intervention or control group (see Supplementary Figure S3.3 in section 8.2.1 for participant flow chart). The sample consisted of predominantly female (n = 253, 84%) participants (mean age = 32; see Table 9), and 57% of the sample had a bachelor's degree or higher level of education. On day 7, the entire sample displayed relatively high intention to prevent unhealthy snacking at cue encounters (mean = 3.27, interquartile range = 3.00, 4.00, scale range 0 to 4). Over the course of the entire study 13,922 SRBAI observations were recorded (mean number of observations per participant = 45, SD = 29). Consequently, 52% (out of 26,605 prompts) of scheduled habit strength measurements were recorded. Initial habit strength was above the scale midpoint (mean SRBAI = 2.63), and this did not differ between the experimental groups ($\chi^2(6) = 9.07$, p = 0.170). Descriptively, habit strength tended to decrease over time across the entire sample (see Table 10), displaying larger rates of change during the first week (full sample mean = -0.07; median = -0.04; range = -0.53 to 0.19) compared to the second week (full sample mean = -0.03; median = -0.02, range = -0.19 to 0.11) of the intervention phase. For experimental group specific habit strength descriptive statistics see Supplementary Table S3.3 in section 8.2.2. Regarding missingness patterns in habit strength time series, the proportion of missing daily observations increased over time similarly across experimental groups (see Supplementary Fig. S3.2 in section 8.2.1).

Table 9. Sociodemographic characteristics of overall sample and by intervention group.

	Overall (N = 313)	Control (n = 50)	Inhibition (n = 44)	Inhibition & reward (n = 44)
Age	32 (25, 37)	32 (24, 35)	33 (25, 41)	32 (25, 39)
(missing)	21	0	4	5
Gender				
female	253 (84%)	35 (71%)	39 (89%)	34 (81%)
male	44 (15%)	13 (27%)	5 (11%)	7 (17%)
other*	5 (1.7%)	1 (2.0%)	0 (0%)	1 (2.4%)
(missing)	11	1	0	2
BMI	25.8 (22.5, 28.6)	26.5 (22.4, 30.9)	24.5 (21.8, 26.7)	26.6 (23.0, 29.1)
(missing)	8	0	0	2
	Substitution (n = 44)	Substitution & reward (n = 44)	Reduced accessibility (n = 44)	Reduced accessibility & reward (n = 43)
Age	31 (24, 37)	33 (26, 37)	33 (27, 38)	31 (25, 36)
(missing)	4	1	4	3
Gender				
female	39 (89%)	37 (86%)	34 (83%)	35 (90%)
male	4 (9.1%)	5 (12%)	6 (15%)	4 (10%)
other*	1 (2.3%)	1 (2.3%)	1 (2.4%)	0 (0%)
(missing)	0	1	3	3
BMI	26.2 (22.3, 27.9)	26.3 (23.0, 28.9)	25.3 (22.6, 28.6)	25.2 (21.3, 28.2)
(missing)	0	0	3	3

Note. *Gender category other combines count from the response options non-binary, questioning, and not specified; BMI: body mass index

Intervention fidelity checks revealed inconsistent adherence to intervention arm specific guidelines, as 35% of implementation intentions did not match the assigned strategy. Additionally, a substantial number of participants reported adaptively using multiple strategies during the study. The frequency of event-contingent questionnaire responses was low, as on average below 9 cue encounters were recorded by one participant over the course of the study. Consequently, reward delivery took place less than anticipated. The manipulation check of reward suggested that the reward features of the app had the intended effect based on high levels of perceived reward. For further details on intervention fidelity and the manipulation check see Supplementary material III section 8.2.4.

Table 10. Descriptive statistics of observed habit strength and indicators of habit degradation for full sample ($N = 313$).

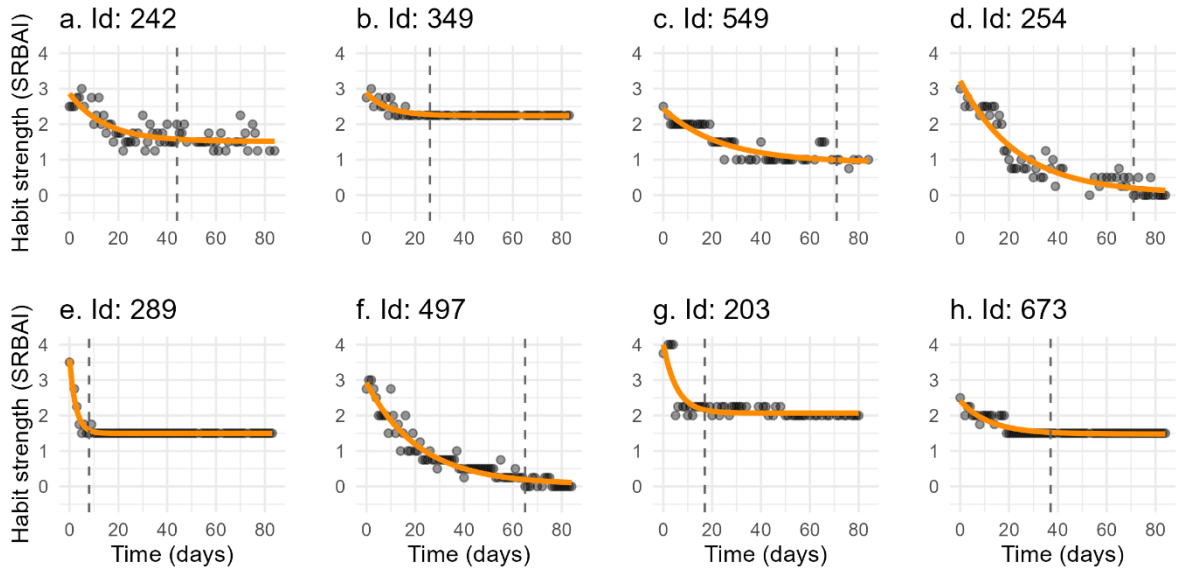
Measure	*n*	Mean	*IQR*
Initial habit strength	313	2.63	2.25, 3.00
Final habit strength*	313	1.53	0.94, 2.08
Week 12 average habit strength	178	1.34	0.59, 2.00
Frequency of reaching and time needed to reach 95% of lower asymptote	66	21.79	6.25, 27.00
Week 1 daily average habit strength rate of change	250	-0.07	-0.11, -0.01
Week 2 daily average habit strength rate of change	250	-0.03	-0.06, 0.00

*Note***.** IQR: Interquartile range (25%, 75%). *Based on the average week 12 habit strength score, or the last available habit strength observation carried forward if no observations were available for week 12.

4.3.1 Within-person habit degradation trajectories

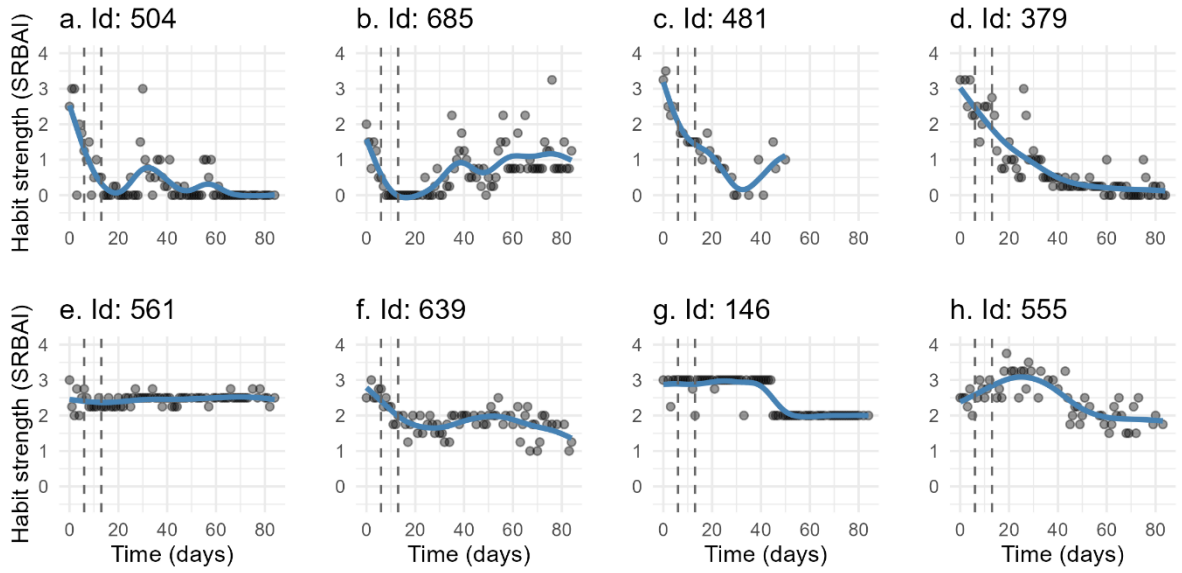
Across the entire sample, within-person asymptotic models were deemed valid for 79 participants, of which in 66 cases 95% of the lower asymptote was reached (see Table 11 for group specific sample sizes). Among within-person asymptotic models that reached 95 % of the lower asymptote, this took on average 22 days (Table 10), ranging from 1 to 79 days. The rate and extent of habit strength decline based on the within-person asymptotic models varied substantially between participants (Figure 11), with some individuals exhibiting rapid degradation and early stabilization (e.g. panels e. & g.), while others showed more gradual declines (e.g. panels d. & f.).

Figure 11. Examples of within-person asymptotic models of habit degradation.



Note. Time ranges from 0 to 84 (intervention phase). Dashed vertical lines indicate when 95% of the lower asymptote is reached. Time series have been selected from all allocated intervention groups. SRBAI: Self-report behavioural automaticity index

Figure 12. Examples of within-person generalized additive models of habit degradation.



Note. Time ranges from 0 to 84 (intervention phase). Dashed vertical lines indicate the latter bound (day 6 and 13) of each rate of change aggregation window. Time series have been selected from all allocated intervention groups. SRBAI: Self-report behavioural automaticity index.

250 participants had sufficient data for estimating GAMs and extracting rate of change values (see Table 11 for group specific sample sizes). Within-person GAMs further highlighted individual differences in habit degradation (Figure 12). Some habit strength trajectories remained relatively stable over time (e.g. panel e.), and others showed stepwise decrease (e.g. panel g.) or more gradual change (e.g. panel f.). Furthermore, some trajectories displayed non-linear decrease similar to asymptotic decline (e.g. panel d.) while others displayed more complex trends such as an initial decrease followed by a partial and transient increase (e.g. panel a.). See Supplementary material section 2.2 for further details on within-person models and examples of asymptotic models and GAMs that did not meet set criteria.

4.3.2 Main analysis

Descriptively, all intervention conditions showed numerically lower adjusted means (Table 11) than the control condition, with the lowest values observed in the substitution and reward condition. However, contrary to hypotheses, the overall magnitude of change in habit strength did not significantly differ between the control and intervention group participants (H1.1.). This was confirmed with the test of equivalence (see Supplementary Table S3.5 in section 8.2.3). There was also not a difference between the intervention groups for magnitude of change (H1.2), with the test of equivalence confirming this null for substitution but not for inhibition or reduced accessibility. Similarly, there was not a difference in magnitude of change for the reward condition (H1.3), but the test of equivalence was undecided for this null finding. There was no indication of group differences for the likelihood of reaching 95% of the lower asymptote (H1.4-H1.6), but these null findings were inconclusive.

For the rate of change, results indicated a significantly greater week-1 rate of change in the intervention groups compared to control. This result remained statistically significant after multiplicity adjustment ($p = 0.042$ for a family of 6 tests). Differences between the strategies or reward condition for week 1 rate of change were not observed (Table 11, H2.1-.3), but there was not credible evidence for these null findings, as equivalence tests were undecided. Regarding week 2 rate of change there was not a difference between control and intervention groups after multiplicity adjustment ($p = 0.234$ for a family of 6 tests) and the test of equivalence and power detection analysis supported this null finding. Again, no differences were observed between intervention groups or reward conditions for week 2 rate of change, which was supported by power detection analysis, but equivalence tests only supported the null for the substitution strategy. Group differences for time to reach 95% of lower asymptote were not observed (Table 11, H2.4-.6), but there was not credible evidence supporting these null findings. See Figure 13 for plots of ANCOVA/ANOVA based main analysis results. For results related to the covariate (initial habit strength) used in the primary analyses, see Supplementary material III section 8.2.3. Sensitivity analyses largely confirmed results from the main analyses (see Supplementary material III section 8.2.5).

Table 11. Estimated marginal means and test statistics of primary analyses.

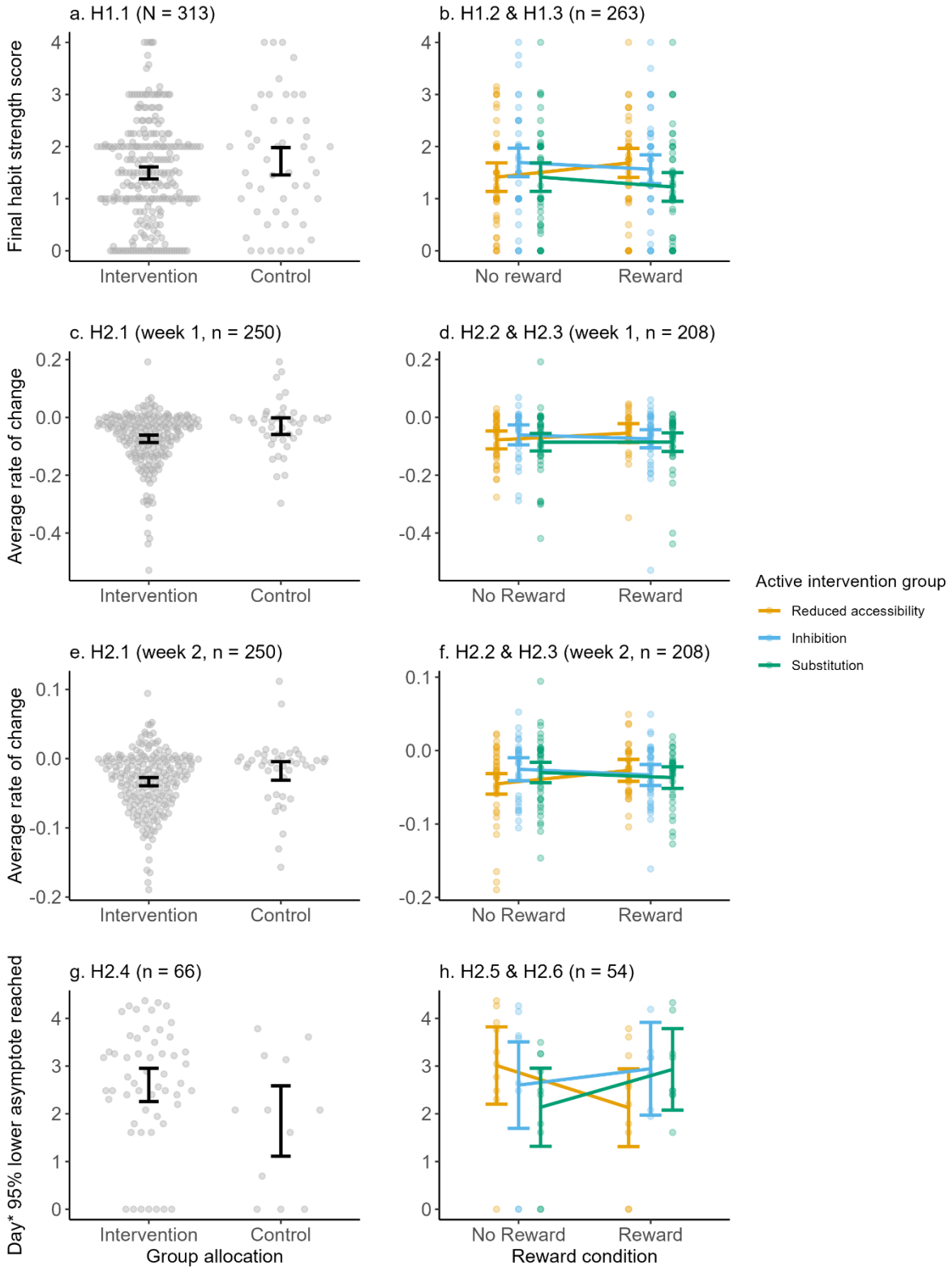
Outcome	Intervention group	Reward condition	*n*	Adjusted mean (*SE*)	95% *CI*	Test statistics
Final habit strength (H1.1-H1.3)	control	not applicable	50	1.72 (0.13)	[1.46, 1.98]	$F(1, 310) = 2.38$, $p = .124$, $ges = .008$
	intervention	not applicable	263	1.49 (0.06)	[1.38, 1.61]	
	inhibition	no reward	44	1.70 (0.14)	[1.42, 1.97]	Intervention group: $F(2, 256) = 2.68$, $p = .071$, $ges = .021$ Reward condition: $F(1, 256) = 0.02$, $p = .892$, $ges < .001$ Interaction: $F(2, 256) = 1.59$, $p = .206$, $ges = .012$
	inhibition	reward	44	1.56 (0.14)	[1.29, 1.84]	
	substitution	no reward	44	1.41 (0.14)	[1.14, 1.69]	
	substitution	reward	44	1.23 (0.14)	[0.95, 1.59]	
	reduced accessibility	no reward	44	1.41 (0.14)	[1.42, 1.97]	
	reduced accessibility	reward	43	1.69 (0.14)	[1.41, 1.96]	
Likelihood of reaching 95% asymptote* (H1.4-H1.6)	control	not applicable	50	0.23 (0.06)	[0.14, 0.37]	$z(1) = 0.480$, $p = 0.631$
	intervention	not applicable	263	0.20 (0.03)	[0.16, 0.26]	
	inhibition	no reward	44	0.23 (0.06)	[0.13, 0.37]	Intervention group: $\chi^2(2) = 0.518$, $p = 0.772$ Reward condition: $\chi^2(1) = 0.007$, $p = 0.933$ Interaction: $\chi^2(2) = 0.002$, $p = 0.999$
	inhibition	reward	44	0.17 (0.06)	[0.08, 0.31]	
	substitution	no reward	44	0.22 (0.06)	[0.12, 0.37]	
	substitution	reward	44	0.21 (0.06)	[0.11, 0.36]	
	reduced accessibility	no reward	44	0.23 (0.06)	[0.13, 0.37]	
	reduced accessibility	reward	43	0.22 (0.06)	[0.12, 0.37]	
Rate of change (H2.1-H2.3, week 1)	control	not applicable	42	-0.03 (0.01)	[-0.06, -0.00]	$F(1, 248) = 7.50$, $p =$ **0.007**, $ges = 0.029$
	intervention	not applicable	208	-0.07 (0.01)	[-0.09, -0.06]	
	inhibition	no reward	30	0.06 (0.02)	[-0.09, -0.03]	Intervention group: $F(2, 202) = 0.93$, $p = 0.395$, $ges = 0.009$ Reward condition: $F(1, 202) = 0.07$, $p = 0.792$, $ges = 0.000$ Interaction: $F(2, 202) = 0.67$, $p = 0.513$, $ges = 0.007$
	inhibition	reward	36	-0.07 (0.02)	[-0.11, -0.04]	
	substitution	no reward	38	-0.09 (0.02)	[-0.12, -0.06]	
	substitution	reward	34	-0.09 (0.02)	[-0.12, -0.05]	
	reduced accessibility	no reward	37	-0.08 (0.02)	[-0.11, -0.5]	
	reduced accessibility	reward	33	-0.05 (0.02)	[-0.09, -0.02]	

Table 11 (continued). Estimated marginal means and test statistics of primary analyses.

Outcome	Intervention group	Reward condition	*n*	Adjusted mean (*SE*)	95% *CI*	Test statistic
Rate of change (H2.1-H2.3, week 2)	control	not applicable	42	-0.02 (0.01)	[-0.03, -0.00]	$F(1, 248) = 4.33$, $p = 0.039$, $ges = 0.017$
	intervention	not applicable	208	-0.03 (0.00)	[-0.04, -0.03]	
	inhibition	no reward	30	-0.03 (0.01)	[-0.04, -0.01]	Intervention group: $F(2, 202) = 0.42$, $p = 0.655$, $ges = 0.004$ Reward condition: $F(1, 202) = 0.04$, $p = 0.846$, $ges = <0.001$ Interaction: $F(2, 202) = 2.03$, $p = 0.134$, $ges = 0.020$
	inhibition	reward	36	-0.03 (0.01)	[-0.05, -0.02]	
	substitution	no reward	38	-0.03 (0.01)	[-0.04, -0.02]	
	substitution	reward	34	-0.04 (0.01)	[-0.05, -0.02]	
	reduced accessibility	no reward	37	-0.05 (0.01)	[-0.06, -0.03]	
	reduced accessibility	reward	33	-0.03 (0.01)	[-0.04, -0.01]	
Days to reach 95% asymptote** (H2.4-H2.6)	control	not applicable	12	6.35 (2.35)	[3.03, 13.30]	$F(1, 63) = 3.43$, $p = 0.069$, $ges = 0.052$
	intervention	not applicable	54	13.53 (2.36)	[9.56, 19.17]	
	inhibition	no reward	8	13.50 (6.07)	[5.45, 33.36]	Intervention group: $F(2, 47) = 0.17$, $p = 0.848$, $ges = 0.007$ Reward condition: $F(1, 47) = 0.06$, $p = 0.813$, $ges = 0.001$ Interaction: $F(2, 47) = 2.26$, $p = 0.116$, $ges = 0.088$
	inhibition	reward	7	18.99 (9.17)	[7.19, 50.18]	
	substitution	no reward	10	8.47 (3.45)	[3.73, 19.24]	
	substitution	reward	9	18.74 (7.96)	[7.98, 44.03]	
	reduced accessibility	no reward	10	20.35 (8.20)	[9.04, 45.78]	
	reduced accessibility	reward	10	8.40 (3.40)	[3.72, 18.97]	

Note. *Adjusted mean (*SE*) represent baseline-adjusted predicted probabilities of reaching 95% of the asymptote, controlling for initial SRBAI scores. These probabilities were obtained from logistic regression models and are marginal means back-transformed from the logit scale to the probability scale for interpretability. Standard errors correspond to these adjusted probabilities, and confidence intervals reflect the uncertainty around the back-transformed estimates. See Table S3.4 in Supplementary material for logistic regression results expressed as odds ratios; **Marginal means were back-transformed to the original scale using the exponential function for interpretability. Standard errors on the back-transformed scale were calculated using the delta method, which approximates the standard error of the exponentiated estimates by multiplying the back-transformed mean by the standard error on the log scale. Confidence intervals were obtained by exponentiating the lower and upper bounds of the confidence intervals on the log scale, resulting in asymmetric intervals on the original scale; ges: generalized eta squared (SS_{effect} / (SS_{effect} + SS_{error}).

Figure 13. Panel plot of ANCOVA/ANOVA based primary analyses.



Note. Plots display results for magnitude of change (panels a & b), rate of change (panels c-f) and time to reach 95% of lower asymptote (panels g & h); *Log-transformed day; Quasi-random noise added to data points in left column plots to improve visualization.

4.4 Discussion

The present study investigated whether candidate habit degradation strategies and reward facilitate habit degradation in daily life at the example of unhealthy snacking habits using outcomes extracted from within-person habit strength time series. In terms of the hypotheses tested, all hypotheses were rejected except for H2.1: habit strength decreases at a faster rate during the first week among intervention group participants compared to control, and this effect was robust when adjusting for multiplicity and across sensitivity analyses. Across all groups, habit strength declined over time, but differences in the magnitude of change, likelihood of reaching 95% of lower asymptote, week 2 rate of change, and time to reach 95% of lower asymptote were not observed, with null findings being informative when comparing the intervention and control groups for magnitude of change and week 2 rate of change. Intervention fidelity checks revealed that adherence to intervention arm specific instructions was variable, and reward was delivered less than anticipated. Hence, findings underscore the complexity of embedding experimental manipulation into daily life settings.

4.4.1 Advancing habit research: theoretical and methodological insights

The present study offers both substantive and methodological contributions to habit research. Substantively, it adds empirical evidence on the temporal dynamics of habit degradation and informs ongoing theoretical discussions on the role of strategies and reward. Methodologically, it provides insight into data collection and modelling approaches suited for capturing within-person habit change in real-world contexts. Particularly in relation to GAMs and rate of change, the present study exhibits a promising approach to harmonizing the quantification of change in the face of heterogeneity.

As a novelty, findings showed that habit strength declined more rapidly among participants in intervention groups than in the control group, particularly during the first week of the intervention phase. One possible explanation for the faster initial degradation in intervention groups is that receiving structured strategy instructions enhanced participants' sense of goal-directed control (Figure 8). Additionally, it is possible that informing the control group about their group allocation may have slowed down rate of change. Within-person asymptotic models further revealed that stabilization—operationalized as reaching 95% of the lower asymptote—varied widely across individuals, ranging from 1 to 79 days. This corroborates previous estimates indicating a similar range of 1 to 65 days (Edgren et al., 2024), highlighting once again the highly idiosyncratic nature of habit processes. This emphasizes the importance of collecting intensive longitudinal data to study habit as only those allow capturing the idiosyncratic, dynamic nature of habit processes in daily life.

Otherwise, the study found no credible evidence in support of differential effectiveness to degrade habits across the three strategies: inhibition, substitution, and reduced accessibility. This aligns with recent observational findings that found no consistent differences between the strategies cue discontinuity, inhibition, and substitution across four health risk behaviour related habits (Edgren & Inauen, 2025a). One possible interpretation is that all strategies are equally effective, and have a common active ingredient, namely non-performance of habitual behaviour (Edgren & Inauen, 2025a) (see Figure 8) or that using an implementation intention (regardless of strategy) is the active ingredient. Alternatively strategy-specific effects may emerge only

over longer timescales than the 3 month range that has been investigated to date (Edgren & Inauen, 2025a). Another explanation may lie in limited experimental control in daily life: inconsistent implementation of the assigned strategies could have diluted potential differences between groups (see below section Implications for experimental intensive longitudinal studies). More broadly, present findings indicating blended use of strategies in daily life raise the question about whether establishing the superiority of individual strategies is a meaningful goal in research. Future work may rather focus on identifying for whom which strategies, or combinations thereof, are most effective in specific contexts.

Similarly, no credible evidence suggested effects of reward on habit degradation. Although this contrasts observational findings showing that days with higher perceived reward were associated with lower habit strength (Edgren & Inauen, 2025a), an important distinction lies in the nature of the reward used in the present study. In the prior study (Edgren & Inauen, 2025a) reward was self-reported and likely captured a more spontaneous and intrinsic experience of reward. Intrinsic reward, in the context of behaviour change, is closely linked to personally relevant goals and identity (Shiota et al., 2021). In contrast, the externally induced reward in this study, delivered through feedback messages and in-app incentives, may have lacked that personal relevance, or may have been redundant with the intrinsic reward participants already experienced. While a laboratory-based study has demonstrated reward effects on habit degradation with feedback messages and monetary incentives (Ceceli et al., 2020), this finding may lack ecological validity – in everyday life, intrinsic and extrinsic rewards may interact in complex ways. Indeed, intrinsic reward has been associated with the formation of health-related habits related to physical activity (Fremling et al., 2025) and nutrition (Di Maio et al., 2022). Finally, the lack of credible evidence of an effect for reward may also relate to limitations in intervention fidelity, as reward was delivered less frequently than anticipated due to limited responding to the event-contingent questionnaire (see below section Implications for experimental intensive longitudinal studies).

This study also highlights key methodological considerations for studying habit degradation in daily life. First, capturing cue encounters and behavioural responses via self-report in daily life remains challenging. Event-contingent reporting of cue encounters was relatively infrequent, suggesting the need for more objective measurement approaches. For example, activity trackers have been used to record cue-behaviour repetition in habit formation (Baretta et al., 2024). Future habit research would benefit from innovative approaches of capturing context-specific cue-encounters and subsequent behaviour as it naturally unfolds. For example, in the study by Buyalskaya and colleagues (2023), radio frequency identification (RFID) was used to objectively track context specific behavioural repetition of hand washing among hospital workers.

Second, this study introduced a novel analytical approach in habit research by estimating the within-person rate of change using idiographic first derivatives from GAMs. This method provides practically interpretable results – for example the rate of change amounts to an average 0.49-point decrease (-0.07*7 days) in the SRBAI score during the first week. Unlike asymptotic models, which may impose unrealistic trends to the data that fit a minority of persons, GAMs offer flexibility in modelling non-linear change (see Figures 11 and 12 plots). As previously demonstrated in the context of habit formation (Baretta et al., 2024), GAMs are well-suited for

modelling the heterogeneous within-person trajectories typical of habit change. Importantly, deriving rate of change from GAMs is a practical solution to harmonizing the quantification of change in heterogenous within-person trajectories. Rate of change, as operationalized here, may serve as a valuable outcome for evaluating interventions, especially in intensive longitudinal studies. For example, this could be used to identify techniques that can support quick gains in forming health-promoting habits.

4.4.2 Implications for experimental intensive longitudinal studies

This study underscores the ongoing tension between ecological validity and experimental control in intensive longitudinal research. As noted above, real-life complexity limited the feasibility of strict experimental manipulation. In particular, the variability in adherence to assigned degradation strategies illustrates the need for closer scrutiny of intervention fidelity in intensive longitudinal research; group assignment alone cannot be assumed to reflect true intervention enactment. In a similar vein, and as noted above in relation to intrinsic and experimentally induced reward, attempting to research the same construct in controlled environments and in real-world contexts may ultimately lead to investigating different phenomena.

Findings also highlight the importance of including a control condition when using intensive longitudinal designs. That no credible evidence suggested differences between intervention and control groups for overall magnitude of change, likelihood of reaching a lower asymptote, or time to reach that asymptote suggests that the self-monitoring inherent in daily diary protocols may itself exert an intervention effect. This possibility is amplified in self-selected samples with strong behavioural intentions as in the present study, as even control group participants may pursue their goals despite receiving no intervention instructions to do so.

Finally, the challenges of event-contingent responding without prompting became evident. Because participants selected idiosyncratic cues, it was not possible to prompt them at the moment of cue encounter. This is a known challenge for event-contingent sampling, as such prompting requires a context detection system (Y.-J. Chang et al., 2015). Consequently, the uptake of event-contingent responding was limited, which can possibly be attributed to higher participant burden that has been shown to be elevated when participants are required to independently remember when to respond (Y.-J. Chang et al., 2015). This limited event-contingent responding in turn compromised the fidelity of reward delivery. This highlights a key design limitation for future intensive longitudinal studies: without tailored prompts or passive sensing capabilities, collecting event-contingent data may place unrealistic demands on participants' self-initiation in real-world contexts. However, this is not to say that a lack of prompting necessarily leads to lower data quantity in intensive longitudinal research. For example, self-initiated event-contingent schedules has been shown to result in a higher number of reported social interactions compared to prompting schedules (Himmelstein et al., 2019).

In addition to these design considerations, this study illustrates a promising analytic approach for bridging idiographic and nomothetic perspectives in intensive longitudinal research. Nested data structure and within- and between- person variability in intensive longitudinal data is often handled with multilevel modelling (Hamaker, 2025; Peugh, 2010). However, in practice when using frequentist statistics this is often constrained by model non-convergence, which is

particularly problematic when dealing with heterogeneous time series data. In this study we showcased an approach to addressing group-level hypotheses while preserving within-person complexity by extracting outcomes from individual time series and within-person model estimates. This approach has the added benefit of making each time series a more salient entity, nudging the researcher to consider idiosyncrasies with more detail, as prompted in the present study with extensive data visualizations (see online repository time series data visualization file https://osf.io/z7tby/).

4.4.3 Limitations

The present study has several strengths including the experimental design, ecologically valid intensive longitudinal assessment of habit strength, and a focus on a range of outcomes which capitalize on the within-person structure of habit strength time series. However, the study also has limitations that should be considered when interpreting findings. As discussed previously, there was suboptimal adherence to experimental manipulations and low levels of engagement with the event-contingent reward manipulation, limiting the confidence in evidence for condition related effects. While sensitivity analyses strengthened the confidence in evidence for habit degradation strategy related findings, generalizability remains a concern as these analyses often dealt with a small subsample of participants. While the study found a robust effect for week 1 rate of change when comparing intervention and control and informative nulls for magnitude of change and week 2 rate of change when comparing intervention and control, the remaining null findings when comparing strategies and reward condition need to be replicated with larger samples. The study focused on unhealthy snacking habits, and findings may not be generalisable to other habitual behaviours. Habit strength was assessed by self-reported perceived automaticity which has received critique (Gardner & Tang, 2014; Hagger et al., 2015; Sniehotta & Presseau, 2012), but this remains the most practical solution available for measuring habit strength in daily life to date (Gardner et al., 2025). Lastly, the sample was predominantly female, relatively young, highly educated, and self-selected. This potentially limits the generalisability of results to broader or different populations.

4.4.4 Conclusions

This study examined the effects of three habit degradation strategies and reward on weakening unhealthy snacking habits in daily life, using intensive longitudinal data and novel within-person analytic approaches. Findings suggest that being instructed on strategy use may accelerate early habit degradation but provide limited indication of differing effects between strategies or receiving reward. Results provide both theoretical insight into the habit degradation process and underscore key design and analytical considerations for investigating naturalistic change in habit strength, and intensive longitudinal research more broadly.

Data availability statement: Data and code used in the formulation of this manuscript and supplementary material are available at: https://osf.io/z7tby/.

5. General discussion

The following general discussion begins by summarising the empirical work presented in Manuscripts I-III (chapters 2., 3., and 4.). This is followed by a reflection on measurement practices for assessing habit strength in daily life, and finally by broader theoretical and practical considerations.

5.1 Summary

Altogether, data from 507 participants and over 25'000 habit strength observations across two studies contributed substantially to advancing habit research and deepening our understanding of habit degradation in the context of health-risk behaviours in daily life. These contributions are summarised below according to the overarching objectives and research questions specified in section 1.5.1.

5.1.1 How does habit degradation occur over time?

This research aimed to describe how habit degradation unfolds over time and how this process can be modelled. Findings revealed that changes in habit strength, based on daily self-reports over periods of up to 12 weeks during a habit degradation attempt, were typically nonlinear and decelerating, with considerable individual variability in the shape of trajectories (Edgren et al., 2024, 2025). In this context, *deceleration* indicates that initial changes in habit strength occurred relatively quickly, followed by a slower rate of change.

Approximately 20% (n = 108) of trajectories displayed a decelerating trend that could be decisively characterised as *stabilizing at a lower bound*, with stabilization occurring within 1 to 75 days. As operationalised in the present studies, stabilization thus occurred in a minority of cases and varied markedly in duration across individuals. Alternative trends were observed when stabilization did not occur, and this accounted for a substantial part of the observed trajectories. Broadly speaking, habit degradation could be characterised by a decreasing trend accompanied by fluctuation and/or a continued decrease until the end of the observed time series. In some cases, large gaps in the data precluded determining whether stabilization had occurred. Additionally, several trajectories reflected unsuccessful habit degradation—for instance, a U-shaped trajectory (habit regaining strength after an initial decline), stable habit (no change over time), or increasing habit strength over time. In sum, several parallels emerged between the habit degradation trajectories observed and those previously reported for habit formation—namely, non-linearity, substantial heterogeneity, and asymptotic approach (e.g. Keller et al., 2021; Lally et al., 2010). These features of the trajectories make modelling habit degradation a non-trivial task, as summarised next.

Across the three manuscripts a variety of modelling techniques were applied, which can be broadly categorised according to *the unit of analys*is and the *functional form of change over time*. Overall, habit degradation can be modelled using a range of analytical approaches, provided that both non-linearity and heterogeneity are appropriately addressed. Along these lines the main methodological insights regarding how to model habit degradation over time are outlined below.

First, regarding the unit of analysis: habit strength time series were modelled at either the individual level (person-specific models) or sample level (multilevel models). Both approaches accommodated non-linearity, but person specific models were arguably better equipped to capture heterogeneity when using frequentist statistics, as was done in this dissertation. This advantage is both conceptual and practical. Conceptually, person-specific—an idiographic approach—focuses on *within-person change*, allowing the unique dynamics of each individual trajectory to be fully appreciated. In contrast, multilevel modelling—a nomothetic approach—aims to *generalise across individuals*. Although multilevel models can account for heterogeneity through random effects, in practice, model selection was often constrained by convergence issues, requiring a compromise between theoretical ideals and practical feasibility. Consequently, person-specific models appear better suited to capturing heterogeneity than multilevel models, at least within a frequentist framework. Importantly, person-specific modelling was also used to generalise across individuals by extracting information from person-specific models in Manuscript III (Edgren et al., 2025).

Second, regarding the functional form of non-linear change over time: 3 approaches proved useful—polynomial functions, asymptotic functions, and generalised additive models (GAMs)—each of which is subsequently summarised considering its utility in modelling habit degradation. **Polynomial functions** are computationally straightforward and somewhat flexible in capturing varying rates of change over time, making them an attractive option for modelling habit degradation. In Manuscripts I and II, cubic polynomial models proved particularly useful for multilevel modelling of habit degradation (Edgren et al., 2024; Edgren & Inauen, 2025a).

Asymptotic functions (including asymptotic and log-logistic functions used in Manuscript I) are computationally more demanding and may face convergence challenges. However, they provide theoretically meaningful parameters that set bounds to the magnitude of change—that is the asymptotes—that allow for theoretically sensible interpretation of results, for example, time for stabilization to occur based on reaching 95% of the asymptote (Edgren et al., 2024, 2025). These models are particularly suitable when observed time series follow an asymptotic pattern of change. However, given the diverse shapes observed in habit degradation trajectories, asymptotic functions were overly restrictive in some cases.

Generalized additive models are the most flexible of the three approaches and are relatively easy to fit. Their ability to model non-linear and heterogeneous trajectories without assuming a specific functional form makes them especially well suited to the idiographic nature of habit degradation. However, this flexibility comes at the cost of losing predefined parameters, which complicates interpretation. In the present analyses, this was addressed by calculating first derivatives to obtain estimates of instantaneous rate of change (Edgren et al., 2025).

In summary, habit degradation is a nonlinear and heterogeneous process that varies considerably across individuals. The findings suggest that person-specific modelling offers a particularly suitable approach for capturing this heterogeneity, while generalised additive models provided the flexibility needed to represent idiosyncratic and potentially complex change patterns over time. Building on this understanding of *how* habit degradation unfolds, the following section turns to the question of *what determines* this process.

5.1.2 What are determinants of habit degradation?

The research conducted aimed to identify determinants of habit degradation, with findings summarised below in terms of person, cue and behaviour related factors. Overall, these determinants were first examined using Study 1 data (Edgren et al., 2024; Edgren & Inauen, 2025a), and the role of reward was subsequently investigated experimentally in Study 2 (Edgren et al., 2025).

Person related factors. Only tentative evidence was found for factors that may facilitate or hinder habit degradation. First, higher trait self-regulation and higher than average within-person intention were associated with lower habit strength, suggesting that these factors may facilitate habit degradation. Second, daily habit strength was higher among individuals experiencing higher-than-average daily stress, indicating that stress may hinder habit degradation.

Cue related factors. Habit strength was higher on days when participants encountered the focal cue compared with days without cue encounters, after controlling for potential non-performance of the habitual behaviour following the cue. Descriptively, the most common types of cues were internal states such as *stress* or *boredom*, actions or events such as *lunch break* or *arriving to work,* and the physical environment such as *sweets in cupboard.* Participants typically described these cues as having high contextual stability. Although these cue characteristics were not associated with habit strength, they provide valuable insight into the nature of the habits that participants were attempting to degrade.

Behaviour related factors. First, no significant differences were found in the habit degradation process over time between sedentary behaviour, unhealthy snacking, alcohol consumption or tobacco smoking (Edgren et al., 2024; Edgren & Inauen, 2025a). However, two related findings offer further insight: (1) initial habit strength was higher for sedentary behaviour and lower for alcohol consumption compared to the combined averages of the other behaviours (Edgren et al., 2024), and that (2) higher initial habit strength was associated to higher daily habit strength (Edgren & Inauen, 2025a). Together, these findings suggest that behaviour-related factors—such as a higher frequency of past repetition—may hinder habit degradation.

Second, daily habit strength was lower on days with non-performance of habitual behaviour compared to days with cue-behaviour performance, and also lower when perceived daily reward was higher than average (Edgren & Inauen, 2025a). These findings support the importance of both non-performance and reward in facilitating habit degradation. However, the experimental manipulation of reward in Study 2 was not found to influence habit degradation (Edgren et al., 2025). This null finding may be attributable to the extrinsic nature of the manipulated reward, whereas in Study 1 (Edgren & Inauen, 2025a) perceived reward was a naturally occurring therefore presumably more intrinsic. In conclusion, reward appears to be a relevant behaviour related determinant that can facilitate habit degradation, though its influence likely depends on the nature of the reward. Intrinsic rewards may be more effective in supporting habit degradation than externally received ones, highlighting a potential avenue for future research. Building on this understanding of *what* influences habit degradation, the following section summarises *how* a habit degradation attempt can be supported.

5.1.3 How can a habit degradation attempt be supported?

Lastly, this research aimed to understand how a habit degradation attempt can be supported. Specifically, this was examined in the context of using theory-based habit degradation strategies and implementation intentions. In this framework, the strategies were of primary interest while implementation intentions served as an evidence based and practical means of operationalising the strategies. Accordingly, the interpretation of results concerning strategy effectiveness applies primarily to this operationalisation.

Supporting their effectiveness, findings from Study 1 suggested inhibition, substitution and cue discontinuity to facilitate habit degradation over time (Edgren et al., 2024). Congruently, experimental evidence from Study 2 showed that inhibition, substitution and reduced accessibility facilitated habit degradation over time (Edgren et al., 2025). Taken together, these descriptive findings suggest that all proposed habit degradation strategies can contribute to habit degradation. However, given that habit strength also decreased in the control group that did not formulate an implementation intention or use an assigned strategy (Edgren et al., 2025), it remains unclear to what extent the observed change can be attributed specifically to the strategies. The active ingredient driving a decrease in habit strength may also relate to factors common to all study conditions, such as heightened self-monitoring facilitated by daily self-report and the intention to change behaviour (Edgren et al., 2025). Furthermore, the findings consistently indicated that the habit degradation process did not differ based on which strategy was employed. Importantly, both studies found that participants tended to prefer substitution (Edgren et al., 2025; Edgren & Inauen, 2025a) suggesting that this strategy is particularly appealing and practical for usage in daily life.

Findings provide encouraging evidence for the feasibility of supporting habit degradation through an automated online platform. Specifically, such a platform can help motivated individuals, and in this scenario minor deviations in the implementation intention intended format appear unproblematic (Edgren et al., 2025; Edgren & Inauen, 2025a). However, the success of independently forming implementation intentions to degrade habits naturally depends on individuals correctly identifying the cues that typically trigger their habitual response (see also section 5.2). Therefore, interventions should also incorporate procedures that assist with cue identification.

Regarding the recommendation of specific habit degradation strategies to be used within implementation intentions, the present findings support substitution as a strong starting point, given that it was frequently the preferred choice among participants (Edgren et al., 2025; Edgren & Inauen, 2025a). Nevertheless, individuals should be informed about all recognised strategies and their effectiveness, and that the adaptive use of several strategies is a natural way to pursue habit degradation.

5.2 Measuring habit strength in daily life

The Achilles heel of measuring habit strength in daily life is the reliance on self-report to infer a construct that resides outside of awareness (Hagger et al., 2015; Sniehotta & Presseau, 2012). In this context, the concern is that an individual's perception of a habit may not coincide with their *true habit* (see section 1.5.2). This fundamental issue will be addressed below in terms of how perceived automaticity can be appropriately used to gauge the strength of true habit

alongside the tentative evidence from the present studies relating to self-report measurement. The section concludes with recommendations for future measurement practices in daily life.

5.2.1 Best present practices

As previously noted in critiques, the validity of self-report habit strength measurement is contingent on awareness of the focal cue associated with a habitual behaviour (Hagger et al., 2015). Accordingly, the focal cue should be explicitly referenced in items measuring perceived habit strength (Sniehotta & Presseau, 2012). The empirical studies in this dissertation showcased procedures that helped participants identify the cue relevant to their habitual behaviour and tailor item wording to account for idiosyncratic cues. This was achieved by providing participants with definitions and examples of cues and habitual behaviours, and starting study participation with a week-long cue identification phase aimed at enhancing awareness of personally relevant cues, and to select one cue-behaviour association to focus on for habit degradation. Because data collection conducted electronically, SRBAI items could be tailored to reference the focal cue selected by participants. Additionally, daily self-report assessments of habit strength reduced recall bias, which has also been noted as a source of concern in the self-report measurement of habit strength (Hagger et al., 2015). Participation in an intensive longitudinal may also have facilitated heightened self-awareness, as has been noted in intensive longitudinal research related to eating disorders (Wilson et al., 2025). In summary, education about habit, self-monitoring during a cue-identification phase, intensive longitudinal data collection, and the tailoring of item wording to each participant's cue and behaviour are recommended practices to help ensure that self-reported habit strength reflects true habit.

More generally, several considerations are important when designing self-report rating scales, especially when measuring constructs such as habit, where the use of self-report is contested. When using Likert scales, researchers should strive to ensure that item comprehension and responses reflect a shared understanding across participants. To this end, it is recommended that all response options be labelled, as this helps to minimise ambiguity. Additionally, it is important to be mindful of the fact that when all response options are labelled, responding differs based on whether the response options are unipolar (e.g. not at all – very much; as done in the presented studies) compared to when response options are bipolar (e.g. disagree strongly – agree strongly) (Steinberg & Rogers, 2022). Importantly, it is arguably ambiguous to what extent varying degrees of *disagreement* with statements assessing perceived automaticity actually reflect perceived automaticity, or for example, confidence in perceiving the *absence of automaticity*. Indeed psychometric work unrelated to habit has shown that latent variables can differ based on whether items are formatted in a unipolar or bipolar manner (Höhne et al., 2022). Unfortunately, these minor yet potentially consequential details of rating scale design may at times be overlooked in habit research (e.g. Rebar, Vincent, et al., 2025).

Supporting the validity of the habit strength measurement approach used in this dissertation, findings showed that perceived changes in habit strength were distinct from cue-behaviour (non-)performance (Edgren et al., 2024), yet cue-behaviour performance was among the strongest predictors of daily changes in habit strength (Edgren & Inauen, 2025a). These findings are reassuring: habit strength is theoretically distinct from behaviour (Gardner & Lally, 2023), but also the product of cue-behaviour repetition (Fleetwood, 2021), and changes in cue-

behaviour performance are central to degrading existing habits (Gardner et al., 2021, 2024; Tobias, 2009). However, a noteworthy and somewhat concerning observation was the observed day-to-day fluctuation in self-reported habit strength. Fluctuations in habit strength (particularly more extreme cases) are unlikely to reflect genuine variation in true habit strength as it is theoretically conceptualised. Instead, large fluctuation may indicate that perceived automaticity captures additional processes beyond true habit. Accordingly, it is relevant to consider how habit measurement in daily life could be further developed, as discussed next.

5.2.2 Future recommendations for measurement

Despite careful planning of measurement procedures, it can still be argued that the perception of habit does not necessarily overlap with true habit. Because the perception of habit strength is distinct from the cognitive construct of habit, it remains unclear what self-report measures truly capture (Hagger et al., 2015). Conversely, some experts argue that individuals can make accurate inferences about their true habits based on experience (Orbell & Verplanken, 2015), a view with which the present author concurs (see section 1.5.2).

This debate remains unresolved, and to advance the field, it is crucial to ask: *how should habit strength measurement be developed?* Given that habit can currently only be measured indirectly (see section 1.2), determining whether self-report measures truly assess habit is inherently limited. For example, convergent validity (Rebar et al., 2018) can only be assessed with other indirect measures. One proposed solution is to use implicit measures to test the concurrent validity of self-reported habit strength (Hagger et al., 2015). However, implicit tests tailored to idiosyncratic real-life habits have yet to be developed.

Conceptually, the advancement of habit measurement can be viewed as a process of *epistemic iteration*—the iterative development of knowledge that may start from reliance on subjective sensations and gradually evolve towards agreed upon standards and scales (H. Chang, 2004). As Orbell and Verplanken (2015) noted a decade ago, substantial progress had been made in the theory and measurement of habit over the preceding 20 years, and this iterative process continues today. The following recommendations outline possible next steps in advancing this work.

First, **qualitative research** is needed to better understand the reflective processes individuals engage in when responding to self-report measures of habit strength. While a think-aloud study of responding to the SRBAI and related measures has been conducted (Gardner & Tang, 2014), extending such work to repeated daily-life measurement contexts would be valuable. Insights from such investigations could further establish the validity and reliability of self-report measures, improve participant instructions, and identify potential novel items for assessing perceived habit strength (Edgren & Inauen, 2025b). Beyond evaluating self-report instruments, qualitative ecological momentary assessment studies exploring contextualised daily life experiences (e.g. Shea et al., 2022) related to habits could generate novel insights to inform future quantitative measurement approaches.

Second, acknowledging the interplay between goal-directed and habit-driven processes as determinants of habitual behaviour in daily life (Rebar, Vincent, et al., 2025; Saunders et al., 2025; Saunders & More, 2025), future studies should **measure goal-directed control (i.e. self-**

regulation) in daily life (e.g. Lopez et al., 2021; Milyavskaya et al., 2021) alongside perceived habit strength, using the same temporal resolution. This approach would capture the complexity of real-world decision-making and provide a more nuanced understanding of how goal-directed and habitual processes jointly influence behaviour—acknowledging laboratory evidence suggesting that behaviour can switch rapidly between these modes of control (Watson et al., 2022). Based on the framework presented on determinants of habit degradation (Figure 6 in section 3.1.2), measuring goal-directed control at the same temporal resolution as habit could be conceptualised as a proximal person-related factor of habit degradation. A good example of capturing a proximal person related factor is to measure momentary intention strength as part of ecological momentary assessment (Rebar, Vincent, et al., 2025). Such measurement practices could also shed light on the processes underlying the restoration of goal-directed control during attempts to overcome unwanted habits, and the processes driving perceived fluctuations in habit strength. Additionally, prompting participants to self-monitor both goal-directed control and perceived habit strength may promote greater self-awareness of how habits influence behaviour. For example, when attempting to avoid habitual behaviour, individuals may reflect on the degree of self-regulation required to resist the habit impulse, and distinguish between behavioural slips (see Orbell & Verplanken, 2010) and deliberate decisions to engage in the behaviour, such as rewarding oneself with a snack after a demanding day.

Third, incorporating **objective measurement of cue encounters and subsequent behaviour** would be essential for improving our understanding of how experiences influence change in habit strength over time. Objective measurement of cue encounters and (non-)performance of habitual behaviour would enable researchers to prompt self-reports at these critical moments. Additionally, with comprehensive data on cue-encounters and subsequent behaviour it would be possible to estimate habit strength—akin to frequency-in-context measurement of habit (Rebar et al., 2018)—with computational modelling (C. Zhang et al., 2022). Using computational models would enable testing and refining theories (Perski et al., 2025) of habit and habit degradation, and help clarify the extent to which perceived habit strength aligns with true habit strength. Furthermore, computational models could be used to disentangle the interplay between habit and goal-directed determinants of behaviour (C. Zhang et al., 2024).

However, collecting such objective data presents significant challenges. Because cues are idiosyncratic, detecting them requires highly personalised systems, which would be resource-intensive even for small samples. Alternatively, researchers could identify naturally occurring scenarios shared across a group of individuals to harmonise cue-encounter detection using technologies such as Bluetooth (e.g. Barnett et al., 2024), RFID (e.g. Buyalskaya et al., 2023), or GPS (e.g. Zhang et al., 2024). Measuring behaviour following a cue encounter also sets limits to the types of behaviours that can feasibly be studied. Physical activity (e.g. Baretta et al., 2024) and sedentary behaviour (e.g. Conroy et al., 2013) can be measured with accelerometers, and smartphone usage can be measured with mobile sensing (e.g. Coyne et al., 2023), but many other behaviours remain difficult to capture objectively. Thus, identifying a cue–behaviour pairing common enough for scalable data collection remains a non-trivial and resource-intensive challenge.

To summarise, future measurement of habit strength in daily life should continue using intensive longitudinal designs with carefully planned measurement procedures, conduct

qualitative research to capture lived experiences of habit, measure perceived habit strength and goal-directed control concurrently, and objectively measure cue encounters and subsequent behavioural performance. Implementing these approaches could contribute meaningfully to the epistemic iteration of our understanding and measurement of habit.

5.3 Theoretical and practical considerations

The following considerations are organised according to the overarching research questions outlined in section 1.5.1. This section starts by discussing temporal dynamics, then addresses reward as a determinant of habit degradation, and concludes with broader reflections on interventions targeting existing habits.

5.3.1 Explaining temporal dynamics in perceived habit degradation

This section offers further reflections on the phenomena of steep initial habit degradation (and potential habit disruption) and day-to-day fluctuation of habit strength—extending beyond the discussion in Manuscript I section 2.4.5, where the focus was primarily on potential sources of error in perceived habit strength. Here, the potential role of *experiencing goal-directed control* in explaining the observed trajectories is considered.

Regarding the experience of a steep initial decline in habit strength, it is plausible that *becoming aware* of cues that typically elicit a habitual response—combined with the increased self-monitoring inherent in intensive longitudinal studies (Edgren et al., 2024, 2025)—fosters a sense of being in control or "turning off the autopilot". Similarly, as discussed in relation to Manuscript III (section 4.4.1), a faster rate of change observed in the intervention group may reflect an enhanced sense of goal-directed control. From an epistemological perspective that acknowledges our understanding of ourselves as grounded in lived experience, such an experience of habit disruption is valid, regardless of whether true habit strength decreased at the same rate.

In a similar vein, perceiving fluctuation in habit strength may reflect variations in self-awareness and intentionality. For example, on one day an individual may feel highly self-aware and deliberate, perceiving their habit as weak, while on another day they may feel more distracted or operate "on autopilot," perceiving their habit as strong—regardless of whether the habitual behaviour occurred. The validity of such explanations could be empirically tested with intensive longitudinal data of simultaneous habit strength and goal-directed control, and with qualitative investigations as suggested in section 5.2.2.

5.3.2 Reward as a determinant of habit degradation

Based on the findings from Manuscripts II and III (Edgren et al., 2025; Edgren & Inauen, 2025a) and as summarised in section 5.1.2, perceived reward—particularly intrinsic facets of reward — appear to be a determinant of habit degradation. However, the present empirical evidence cannot fully capture the many dimensions of reward that may influence habit degradation. Accordingly, this section discusses reward in greater depth, first by considering its multifaceted nature, and then by outlining how these facets may inform the development of habit degradation interventions.

Multifaceted reward value. A comprehensive understanding of reward in the context of health-risk behaviour habit degradation may require consideration of at least three facets: (1) the reward from non-performance of the habitual behaviour, (2) the reward associated with performing an alternative goal directed behaviour, and (3) the reward associated to the unwanted target behaviour. Habit research in neuroscience has emphasized the role of collaborative goal-directed and habit-related brain activation networks in influencing behaviour (Malvaez, 2020; Watson et al., 2022), with reward networks also implicated (Burton & Balleine, 2022) contributing to the reinforcing nature of reward and subsequent *wanting* (Berridge & Robinson, 2003). From a psychological perspective, the interplay between goal-directed control, habit, and reward has similarly been articulated as a nuanced, collaborative process (Rebar, Rhodes, et al., 2025). This perspective highlights the importance of accounting for the *liking* and *wanting* associated with both habitual and goal-directed behaviours to fully understand determinants of behaviour. Consequently, habit research could benefit from adopting a more nuanced conceptualisation of reward. In the present dissertation, the focus was on the reward associated with *not performing* a habitual behaviour—for example, *feeling joy and satisfaction from avoiding a glass of wine with dinner.* Naturally, individuals may also experience reward from performing an alternative goal-directed behaviour. This has been demonstrated with habit substitution of commuting (Di Maio et al., 2025), where experiencing reward from a new commuting behaviour was associated with gains in habit strength for that alternative behaviour. Similarly, an individual might find pleasure in replacing wine with sparkling water at dinner.

In the context of degrading health-risk behaviours, the unwanted behaviour (e.g., drinking wine or smoking) may also carry its own reward value—constituting a *third facet* of reward relevant to habit degradation. This aspect to reward, described as part of hedonic motivation (Williams, 2019), reinforces engaging in a health-risk behaviour and contributes to habit formation (Rebar, Rhodes, et al., 2025). Notably, hedonic motivation is conceptualised as a partially automatic, cue-triggered determinant of behaviour much like habit. In the context of health-risk behaviours, habit and hedonic motivation may thus manifest simultaneously as urges that conflict with goal-directed intentions (Rebar, Rhodes, et al., 2025). These conceptualisations warrant greater attention in future habit degradation research, and illuminate that also strong desires or cravings (Kavanagh et al., 2005) may be a determinant that hampers habit degradation. This hedonic facet of reward may also be viewed in terms of having facilitated engagement with the target behaviour beyond the focal cue-behaviour pairing. In more extreme cases this may be linked to addiction. Notably, substance use disorder may be influenced by an imbalance between goal-directed control and habit activation networks, where the imbalance may be due to abnormal habit or various forms of impairment in goal-directed control (Vandaele & Janak, 2018). This further underscores the importance of accounting for the past and present reward value attached to unwanted health-risk behaviours when attempting to degrade associated habits.

Measuring all noted facets of reward—reward from *not performing* a habitual behaviour, the reward from *performing* a goal-directed alternative, and the reward associated with the unwanted target behaviour—would therefore provide a more complete understanding of how reward influences habit degradation. Embracing this line of thought is subsequently highlighted

with an example: Moments of change are recognized as potent windows of opportunity for changing habits, such as a new environment free of old cues that previously triggered habitual responses (Verplanken et al., 2018; W. Wood et al., 2005). The potency of moments of change may partly reflect information processing and re-evaluation of priorities and goals (Verplanken et al., 2018). However, it is also valuable to consider how *reward values* may shift during these moments. Shifts in desirability—such as a decrease in the appeal of the habitual behaviour and / or an increase in the reward value of the goal-directed alternative—may play a role in behaviour change and perceiving change in habit strength. For instance, an individual may initially perceive a smoking habit as resistant to change due to recurring urges to smoke. However, becoming pregnant may substantially reduce the desirability of smoking while increasing the desirability of abstaining. In such a case, an individual may quit smoking and perceive multiple smoking habits as disrupted.

To summarise, comprehensively understanding habit degradation may require conceptualising reward as a multifaceted construct encompassing distinct values associated with habitual behaviours, non-performance of habitual behaviour, and alternative goal-directed behaviours that changes over time. Importantly, for health-risk behaviours reward linked to the unwanted behaviour may be particularly influential. Consequently, interventions should also consider how reward dynamics can be leveraged, as discussed below.

Interventions informed by reward. Habit degradation interventions for health-risk behaviours may benefit from accounting for the reward values of both habitual and goal-directed behaviours. Future interventions may benefit from assessing how individuals perceive the desirability of each and tailoring intervention content accordingly. For instance, if the goal-directed behaviour is already perceived as highly desirable relative to the habitual behaviour, less intensive intervention content may suffice. Conversely, when the habitual behaviour is perceived as more rewarding—as understandably may be the case with unwanted habits (Gardner et al., 2021)—additional intervention components may be needed to 'level the playing field'.

Given that intrinsic reward appears to facilitate habit degradation (Edgren et al., 2025; Edgren & Inauen, 2025a), interventions could aim to capitalise on this intrinsic reward of non-performance or alternative behaviours. For example, reframing the act of not smoking at the bus stop as a 'want-to' goal integrated with one's identity could make abstaining inherently rewarding in the moment. Facilitating spontaneous experience of intrinsic reward in the moment may not require technically complex solutions (e.g., via mobile applications). Instead, approaches that strengthen intrinsic motivation—such as motivational interviewing (Miller & Rollnick, 2023)—may be more suitable. Indeed motivational interviewing has been previously used to facilitate behaviour change related to among others, physical activity, diet, smoking, alcohol and substance use (Lindson et al., 2019; Morton et al., 2015; Schwenker et al., 2023).

Finally, in relation to the substitution strategy, one approach to enhance the reward value in the moment is to make rewarding aspects more salient. To this end, techniques such as engaging in mental simulation and imagery of the pleasurable aspects (Muñoz-Vilches et al., 2019; Papies et al., 2020; Shiota et al., 2021) of the alternative non-habitual response can be used—for example *savouring crisp and refreshing sparkling water* when substituting wine.

5.3.3 Perspectives to habit degradation strategies and interventions

The presented findings (Edgren et al., 2025; Edgren & Inauen, 2025a) did not indicate differences between the examined strategies for degrading a habit. These findings support the theoretical proposition that non-performance is central to habit degradation, as proposed by Tobias (2009). However, as noted in Manuscript III (Edgren et al., 2025), comparing strategies against each other may not be a productive approach, since in everyday life individuals may often use strategies in combination rather than isolation. Furthermore, implementation intentions represent only one means of operationalising these strategies (Edgren & Inauen, 2025a) and does not enable rigorous testing of their comparative effectiveness (Edgren et al., 2025). Beyond these considerations, it can also be argued that the strategies may lack theoretical distinctiveness, as discussed next.

Framing degradation strategies. The boundaries between strategies are not always clear. First, substitution inherently involves also using inhibition (Gardner & Lally, 2018). Second, cue discontinuity may in practice also entail substitution. For example, in the hallmark study of cue discontinuity (Walker et al., 2015), participants were observed to create new commuting habit in place of their old commuting habits. Third, as discussed in Manuscript II (Edgren & Inauen, 2025a) section 3.1.2, reducing behavioural accessibility is a specific type of inhibition. Taken together, the overlapping nature of these strategies suggests it may be advisable to reconsider how habit degradation strategies are conceptualised such that this theory is more ecologically valid. One possible approach could be referring to a 'habit degradation toolkit' that represents all strategies as part of a whole. Within this framework, individual strategies could be further differentiated based on characteristics such as underlying mechanisms, the need for prior planning, and the need for willpower in the moment.

Intervention effects on unconditional behaviour. An unexplored perspective on habit degradation interventions is their potential impact on behaviour change beyond the focal cue-behaviour pairing. In the context of habit formation, evidence suggests that brisk-walking related habit strength is positively associated with unconditional behaviour engagement (i.e. engagement beyond cue-contingent repetition) raising questions about underlying mechanisms (Baretta et al., 2024) and its implications for intervention development. Clarifying whether habit degradation interventions can similarly facilitate unconditional behaviour change would be valuable, as doing so would enhance their practical relevance.

5.4 Strengths and limitations

The strengths of the present work span the subject matter, methodology and reporting. Specifically, this dissertation provides novel, and in some respects, pioneering contributions to habit research by investigating the temporal dynamics, determinants and strategies of habit degradation. Furthermore, the use of intensive longitudinal data collection focused on personally relevant habits informed by cue identification phases ensured ecologically valid investigation of naturally occurring habits in everyday life. Methodologically, a wide range of analytical procedures were employed. This included person-specific modelling with several functional forms, multilevel modelling, and extracting different indicators of change to capture habit degradation comprehensively. Furthermore, the qualitative assessment of personally defined cues, implementation intentions and strategy used, as well as extensive sensitivity

analyses speak on behalf of comprehensive and rigorous practices. In terms of reporting, the research adhered to open science standards through preregistration, transparent and detailed reporting (including extensive supplemental material), and the sharing of both data and code.

The presented research also has limitations that should be acknowledged. The studies were conducted with predominantly female and highly educated convenience samples with strong intentions towards behaviour change, which sets limits to the generalisability of results. Moreover, the results are primarily based on unhealthy snacking related habit degradation (n = 370) and to a lesser extent sedentary behaviour, alcohol consumption and tobacco smoking (n range = 39 – 57), which further constrains the generalisability of results. It is also important to note that findings pertain to singular cue-behaviour pairings, and are therefore not applicable to broader unconditional behaviour change. Additionally, the empirical work presented in this dissertation primarily focused on advancing basic research concerning habit degradation in daily life. Consequently, aspects relevant to intervention research—such as stakeholder involvement in intervention development and (un)intended impact evaluation (Skivington et al., 2021)—fell outside the scope of this work. Lastly, as habit strength was measured by self-report results reflect perceived habit strength, and it is undetermined to what extent this corresponds to true habit strength.

5.5 Conclusions

Returning to the question posed at the outset—*are habits truly as hard to overcome as conventional wisdom suggests?*—the findings of this dissertation provide a reassuring answer: no, health-risk behaviour related habits appear to be susceptible to change. Central to degrading such habits is refraining from performing the habitual behaviour, experiencing reward during the degradation attempt, and presumably heightening self-monitoring and strengthening a sense of goal-directed control. The present results demonstrate that degradation can be successfully pursued with the help of implementation intentions that facilitate the use of various habit degradation strategies.

However, the process by which habits degrade is far from uniform, with substantial variation evident across individuals. These idiosyncrasies reflect unique lived experiences, and should be embraced in research, as doing so is essential to understanding habit as it is expressed in everyday life. To this end, flexible person-specific quantitative analytic approaches are encouraged along with qualitative work. Looking ahead, reward-sensitive habit degradation research combined with progressive approaches to measuring habit strength and related constructs hold promise for realising the full potential of this research field and hopefully for improving and sustaining individual well-being.

6. Supplementary material I

This is the supplementary material that accompanies the published article (Manuscript I): Edgren, R., Baretta, D., & Inauen, J. (2024). The temporal trajectories of habit decay in daily life: An intensive longitudinal study on four health-risk behaviours. Applied Psychology: Health and Well-Being, aphw.12612. https://doi.org/10.1111/aphw.12612

6.1 Methods

6.1.1 Measures

Target behaviours. Unhealthy snacks were defined as foods consumed between main meals that are high in fat, sugar, and/or salt and low in micronutrients (Evans et al., 2017; Verhoeven et al., 2014) with examples of unhealthy snacks given based on food categories with high fat/sugar content (Kelly et al., 2007) as similarly done previously (Inauen et al., 2016). Participants were instructed to consider 1 serving of unhealthy snacks as approximately 1 handful or 30 grams in weight (FoodDrinkEurope, 2023). One unit of alcohol was described to correspond to 33cl of 5% beer, 13cl of wine or 4cl of 40% liquor (World Health Organization, 2001). For estimating number of tobacco product units consumed participants were instructed to consider cigarette, cigar, and pipe smoking.

Intention. Intention strength was assessed with the items "To what extent do you intend to reduce your [target behaviour] when you encounter the selected situation [selected cue]?" and "I plan to reduce my [target behaviour] tomorrow in my chosen situation ([selected cue])?". Items were measured on 5-point Likert scales (scored 0-4, with higher scores indicating stronger intention). Items were averaged to derive one score for the construct.

6.1.2 Procedure

Exerts of information and instructional texts provided to participants in the unhealthy snacking group on day 7 are subsequently displayed. Note that these exerts are translated from German, and do not cover all information provided to participants (for example, the definition for habit was provided during the first day of participation, and readily available on all subsequent days during the first week). The content of texts provided to the other behaviour groups are the same, but examples are made in reference to the relevant target behaviour.

Now it's time for you to choose a snacking habit that you would like to change during the study. First, we would like to explain what a habit is and how to change habitual snacking behaviour. Understanding this is important for participation in the study.

Habitual behaviour

By "habitual behaviour" we mean a behaviour that has become automated due to constant repetition when a cue occurs and has therefore become routine. Cues can be objects, people, routines or times, for example. A strong habitual behaviour is then performed almost automatically when the cue occurs. In order to break a habitual behaviour, it is therefore important to first find the cue.

Here are a few examples:

Anna eats a pastry during her afternoon coffee break. Personal cue: Afternoon coffee break (routine)

Anna sees the cookie tin in her kitchen cupboard and grabs a cookie straight away. Personal cue: cookie tin (object)

At 4 p.m. Anna sits down and eats a cookie. Personal cue: 4 p.m. (time).

[Page break]

Now it's your turn to choose a cue for your snack habit that you want to change. Remember, you should focus on this cue for your snacking habit during the 12-week study period.

Choose a cue...

- **...that you encounter frequently,**
- **...that tempts you to eat unhealthy snacks most of the time**
- **...and for which you feel confident to stop or reduce your snack consumption during the study.**

Below we have listed the cues that you have observed and reported in your diary over the past week. You can now choose a cue that best meets the criteria above (frequent occurrence, usually leads to snacking, you are confident that you can stop/reduce snacking for this cue).

You are also welcome to choose a cue that is not listed here if you can think of one that fits even better. This will be the snack habit you are trying to change during the study.

[Reported cues inserted here]

I select the following cue: [Open response answer field]

[Page break]

Now it's time to decide how you want to reduce your unhealthy snack consumption in your chosen situation "[selected cue inserted here]".

First, take a look at this description of how habits can be changed:

Changing habits

The key to changing a habit lies in the following three steps:

- First, identify the cues that cause the habitual behaviour. You have just completed this step!
- Secondly, you need to create a plan for how you want to behave in future when you encounter the cue.
- And thirdly, the plan must be consistently implemented when you encounter the cue.

[Page break]

Now we come to the second step for habit change: you create a plan for how you want to behave in the future when you encounter the cue.

There are different ways to stop or reduce habitual behaviour when you encounter the cue. You can...

- ... replace the behaviour with something else (substitute action).
- ... prevent yourself from performing the behaviour (inhibition).
- ... prevent yourself from encountering the cue (preventing the situation).

Here are a few examples to illustrate this:

Anna wants to change her habit of eating a pastry with her coffee in the cafeteria in the afternoon. She considers 3 ways in which she can achieve this:

- She could plan to eat a fruit instead of a pastry (replacement action), or
- She could plan to think about her goal of not eating a pastry (inhibition), or
- She could plan to stop drinking coffee in the afternoon (prevent situation).

In the following part, you can switch back and forth between the questions to decide on a plan.

The subsequent guidelines were presented in small chunks using multiple choice questions, where the guidelines displayed differed depending on the answer provided previously. This step-wise presentation of instructions (with the possibility to go back-and-forth through the questionnaire) was used to facilitate comprehension and to make an informed decision about how to proceed with study participation.

6.1.3 Missing value imputation

Non-consecutive missing observations were imputed with the Kalman filter using the R package imputeTS (Moritz & Bartz-Beielstein, 2017). The decision to impute only non-consecutive missing values was a conservative effort to improve data quality. Preliminary testing of imputing longer missing gaps indicated that imputed values tend to gradually stabilize around a given value, mimicking the approach of an asymptote which cannot be assumed to be correct.

6.1.4 Person-specific modelling

Model formulae. The formulae of the models predicting habit strength (y) by time are presented below. The predictor variable time was rescaled to vary from 0 to 84, where 0 corresponds to the first habit strength measurement (day 7 of study participation) and 84 corresponds to the last day of study participation (day 91).

Constant: $y_{ti} = \beta_{0i} + e_{ti}$

Linear: $y_{ti} = \beta_{0i} + \beta_{1i}(Time_{ti}) + e_{ti}$

Quadratic: $y_{ti} = \beta_{0i} + \beta_{1i}(Time_{ti}) + \beta_{2i}(Time_{ti})^2 + e_{ti}$

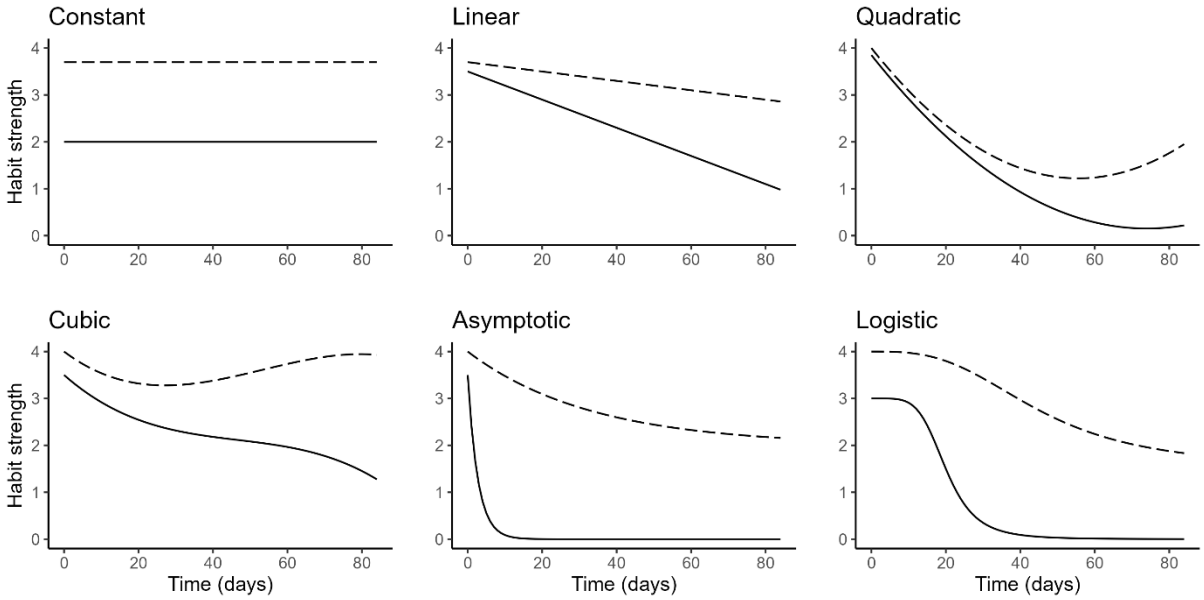
Cubic: $y_{ti} = \beta_{0i} + \beta_{1i}(Time_{ti}) + \beta_{2i}(Time_{ti})^2 + \beta_{3i}(Time_{ti})^3 + e_{ti}$

Asymptotic: $y_{ti} = \beta_{ASYMi} + (\beta_{R0i} - \beta_{ASYMi}) * \exp(-\exp(\beta_{LRCi}) * Time_{ti}) + e_{ti}$

Log-logistic: $y_{ti} = \beta_{LASYMi} + \frac{\beta_{UASYMi} - \beta_{LASYMi}}{1 + \exp[\beta_{SMIDi}(\log(Time_{ti}) - \log(\beta_{XMIDi})]} + e_{ti}$

To clarify the asymptotic model parameters, the *ASYM* represents the asymptote (in case of a decreasing trend, the lower bound) of habit strength, *R0* represents the value of habit strength on day 0, and *LRC* represents the natural logarithm of the rate constant at which habit strength approaches the asymptote. To clarify the log-logistic model parameters, *LASYM* and *UASYM* represent the lower and upper asymptotes, respectively, *SMID* represents the slope at the midpoint between the asymptotes, and *XMID* represents the time at which habit strength reaches the midpoint between the asymptotes (Onofri, 2019). For fitting person-specific asymptotic and logistic models the R package nls.multstart (Padfield & Granville, 2020) was used, as it enables using multiple starting values iteratively. Example plots of the 6 models of interest are displayed in Figure S1.1.

Figure S1.1. Examples of potential habit strength trajectories in the context of trying to degrade a habit based on constant, linear, quadratic, cubic, asymptotic, and logistic models.



Note. Dashed lines represent trajectories of habits with higher initial strength, less pronounced decrease, or transient decrease in habit strength.

Procedure for identifying "valid fitted values". The following section provides a description of the 4-step procedure devised to identify whether the person-specific model fitted values provided a valid description of the habit trajectory.

1. Identify cases where fitted values decrease over time based on model parameters. In the case of best-fitting polynomial models, this distinction was made on the linear parameter. While the linear parameter alone does not definitively describe the overall trend of polynomial models, within the present sample a positive linear parameter distinguished whether an overall decrease in habit strength was absent.
2. Identify cases where model selection is not impacted by individual observations. To test the robustness of model selection, models were rerun with shortened timeseries for cases with long gaps of missing values (≥ 15 days) in the second half of the time series. Here, singular observations that followed a long missing gap were removed to test whether these single observations influenced model selection. In cases where the best fitting model changed, model fitted values were considered nonvalid.
3. Identify cases where the best fitting model shows sufficient absolute fit. Based on visual inspection, the root-mean-square-error (RMSE) cut-off value of 0.33 was deemed to distinguish accurate from inaccurate models well. Substantially, as RMSE is on the same scale as the dependent variable (Self-report Behavioural Automaticity Index; SRBAI), this cut-off indicates that the average difference between the observed and predicted value is approximately one third of a Likert point (on a 5-point Likert scale).
4. Identify cases where time series do not contain missing gaps of observations longer than 21 days in length. Visual inspection suggested long missing gaps to often be accompanied by seemingly unrealistic fitted values of habit strength. Consequently, models of time series

containing missing gaps of at least three weeks (21 days) in length were considered nonvalid.

6.1.5 Group-level models

Multilevel modelling was conducted using the R package lme4 (Bates et al., 2015).

6.1.6 Divergence from protocol

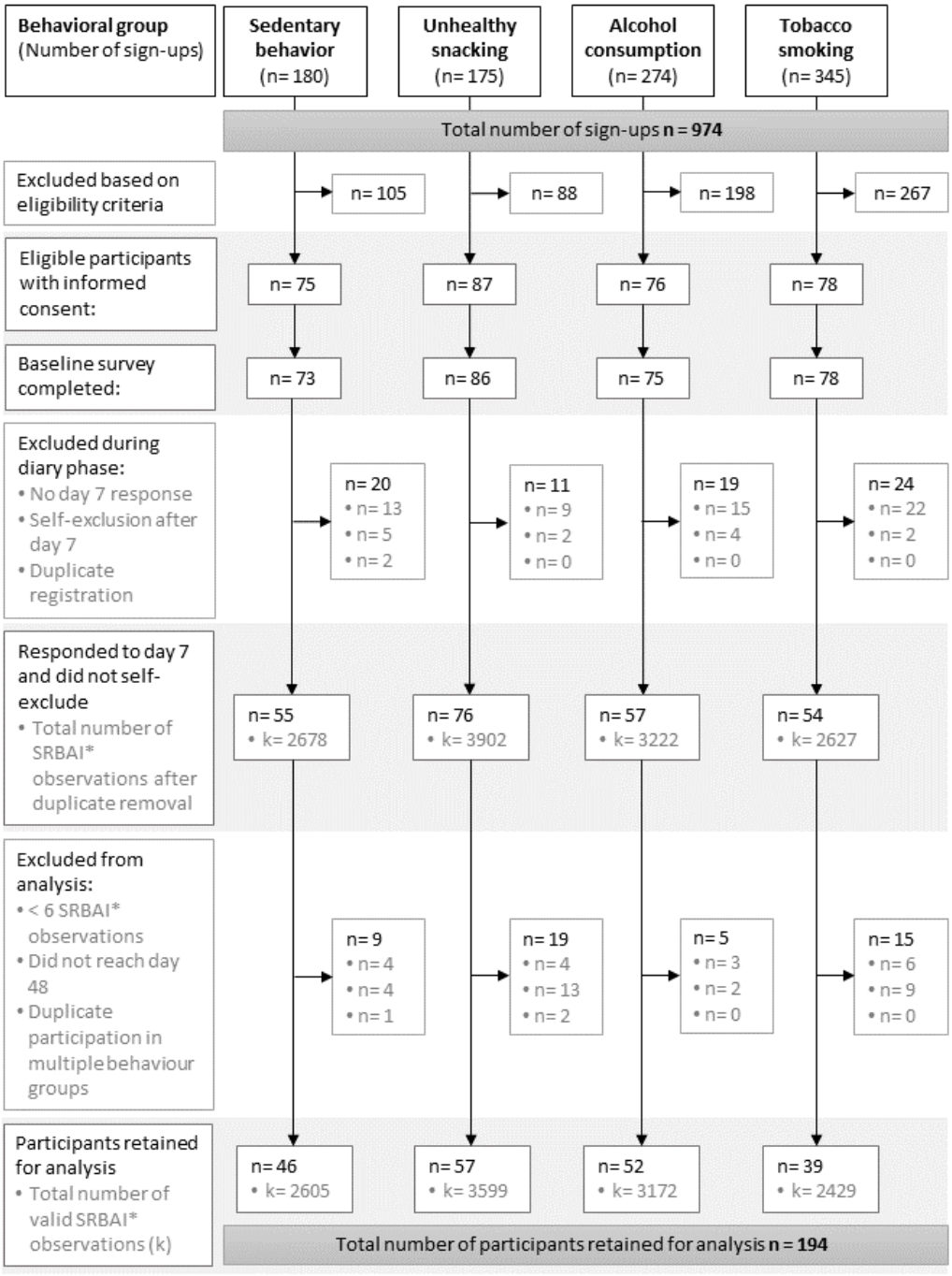
First, the best fitting person-specific model was determined with the BIC index, opposed to RMSE. This deviation was done to favour parsimony in model selection. Second, the logistic model used is a 4-parameter log-logistic model, opposed to the 5-parameter Richard's curve (Richards, 1959) logistic model. This deviation was due to a lack of success in fitting the Richard's curve. Lastly, explorative methods were used to address the research question of comparing the habit decay process between behavioural groups.

6.2 Results

6.2.1 Sample characteristics

See Figure S1.2 for flow chart of participant retention. Comparison of sociodemographic characteristics between participants included for analysis and those excluded indicated no group difference based on age, gender, Body Mass Index (BMI), civil status, occupational status, or highest level of education. Regarding the day 7 survey, intention to change behaviour was higher in the sample included for analysis (*Mdn* = 3.5. *SD* = 0.76; *n* = 194) compared to the excluded sample (*Mdn* = 3.0, *SD* = 0.92; *n* = 58). Also, among participants who created an implementation intention on day 7, there was a difference in the strategy chosen by participants in the included and excluded samples. Specifically, a higher proportion of participants in the excluded sample selected the discontinuity strategy (19%, *n* =11) compared to the analysed sample (7%, *n* =13), and a lower proportion of the excluded sample (26%, *n* = 15) selected the inhibition strategy compared to the analysed sample (35%, *n* = 68). For comprehensive baseline characteristics of the sample included for analysis see Table S1.1; here, concerning group comparisons, post-hoc pairwise behavioural group differences for highest level of education and occupational status could not be confirmed after Bonferroni's adjustment of p-values.

Figure S1.2. Flow diagram of participant retention.



Note. SRBAI*: Self-Report Behavioural Automaticity Index

Table S1.1. Comprehensive baseline sample characteristics by behavioural group ($N = 194$).

	N	Overall	SB, $N = 46$	US, $N = 57$	AC, $N = 52$	TS, $N = 39$	*p*
Baseline variables							
Age	194	39 (32, 49)	34 (30, 42)	38 (30, 45)	44 (36, 53)	40 (34, 51)	<0.001
Gender	183						<0.001
Female		137 (75%)	37 (84%)	49 (89%)	24 (51%)	27 (73%)	
Male		45 (25%)	6 (14%)	6 (11%)	23 (49%)	10 (27%)	
Other		1 (0.5%)	1 (2.3%)	0 (0%)	0 (0%)	0 (0%)	
BMI	183	23.5 (21.8, 27.5)	22.1 (20.8, 25.3)	24.8 (21.9, 27.9)	24.7 (22.0, 27.9)	23.5 (22.0, 26.6)	0.109
Civil status	183						0.133
In relationship		66 (36%)	22 (50%)	22 (40%)	13 (28%)	9 (24%)	
Married		55 (30%)	10 (23%)	20 (36%)	16 (34%)	9 (24%)	
Single		39 (21%)	8 (18%)	9 (16%)	11 (23%)	11 (30%)	
Divorced		21 (11%)	3 (6.8%)	4 (7.3%)	6 (13%)	8 (22%)	
Reg. relationship		1 (0.5%)	1 (2.3%)	0 (0%)	0 (0%)	0 (0%)	
Widowed		1 (0.5%)	0 (0%)	0 (0%)	1 (2.1%)	0 (0%)	
Highest level of education.	183						0.003
University studies		105 (57%)	32 (73%)	30 (55%)	27 (57%)	16 (43%)	
Vocational training		55 (30%)	7 (16%)	14 (25%)	19 (40%)	15 (41%)	
High school / voc. dipl.		17 (9.3%)	4 (9.1%)	10 (18%)	1 (2.1%)	2 (5.4%)	
Secondary school dipl.		6 (3.3%)	1 (2.3%)	1 (1.8%)	0 (0%)	4 (11%)	
Primary school dipl.		0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
Occupation	183						0.043
Employed		145 (79%)	34 (77%)	44 (80%)	42 (89%)	25 (68%)	
Homemaker		13 (7.1%)	2 (4.5%)	6 (11%)	0 (0%)	5 (14%)	
Student		11 (6.0%)	6 (14%)	3 (5.5%)	1 (2.1%)	1 (2.7%)	
Retired		10 (5.5%)	1 (2.3%)	2 (3.6%)	3 (6.4%)	4 (11%)	
Unemployed		3 (1.6%)	1 (2.3%)	0 (0%)	1 (2.1%)	1 (2.7%)	
(Re)training		1 (0.5%)	0 (0%)	0 (0%)	0 (0%)	1 (2.7%)	

Note. Continuous variables reported with Median (interquartile range) and p-values based on Kruskal-Wallis rank sum test; Categorical variables reported with n(%) and p-values based on Fisher's Exact Test for Count Data with simulated p-value (based on 2000 replicates); SB: Sedentary behaviour; US: Unhealthy snacking; AC: Alcohol consumption; TS: Tobacco smoking; BMI: Body Mass Index; SRBAI: Self-Report Behavioural Automaticity Index; reg.: registered; voc.: vocational; dipl.: diploma

Examples of cues selected by participants on day 7 from the sample retained for analysis are displayed in Table S1.2. These are examples of cues in response to which participants wanted to change their habitual target behaviour. Of note, the implementation intentions participants formulated often incorporated multiple cue categories that were not all evident in the initial cue selected (e.g. *If I come home stressed after work*…).

Table S1.2. Examples of cues selected by participants by behavioural group.

	Behavioural group			
Cue category	Sedentary behaviour	Unhealthy snacking	Alcohol consumption	Tobacco smoking
Physical context Cues related to the physical environment or objects	- Office chair - Train	- Kitchen - Shop	- Sports on TV	- In the car - Alcohol
Social context Cues relating to the person(s) present or absent	- Lunch in a group - Meeting friends	- Being alone - Being in the presence of someone eating snacks	- With a friend in the evening - Alone at home	- With people who smoke - Alone at home
Emotion / Cognition Cues related to emotions, physical sensations or thoughts	- Tired - Desire to relax	- Desire for something sweet - Stress	- Stress - Boredom	- Boredom - Being annoyed
Event / temporal context Cues such as actions, routines, events that are about to start, are taking place or have already taken place. Also temporal information such as times of day	- Breakfast - Watching TV	- Lunch break - At 13:00	- After work - Dinner	- Morning coffee - Waiting for the bus

Note. Definitions to cue categories are provided in the left column. Cue categories were created inductively based on participants' responses. The examples provided are not a comprehensive overview of cues selected.

6.2.2 Description of missing SRBAI observations

Concerning missing SRBAI observations in the sample included in analyses, one participant did not have any missing SRBAI observations. For the remaining 193 participants the mean number of missing SRBAI observations was 24 (29 %; out of maximum 84). The median longest missing gap for the time series was 3 days and ranged from 0 to 62 days. For descriptive information about missing SRBAI observations after imputation see Table S1.3.

Table S1.3. Descriptive statistics of missing SRBAI values in time series (N = 194) after imputation.

	Mean (*SD*)	Median (min, max)
Percentage missing	21.19 (25.56)	7.06 (0, 90.59)
Number of missing gaps	3.07 (3.06)	2 (0, 15)
Average missing gap size (days)	4.95 (7.02)	2.33 (0, 42)
Longest missing gap (days)	10.14 (14.45)	3 (0, 62)

Note. SRBAI = Self-Report Behavioural Automaticity Index; *SD* = Standard deviation; SRBAI was measured daily for 84 days. Only non-consecutive missing values were imputed.

6.2.3 Person-specific modelling

Table S1.4 displays the frequencies of best-fitting person-specific models by behavioural group. Findings show that the asymptotic and logistic were most often the best fitting models across the sample. Concerning the absolute fit (RMSE) of best fitting models, a significant difference between the models was evident (see Table S1.5). Post-hoc pairwise comparison revealed that RMSE of the logistic model was significantly smaller than that of the linear and quadratic models, indicating better absolute fit. Percentage of missing values and longest missing gap of SRBAI measurements did not significantly differ between the best fitting person-specific model types (see Table S1.6).

Table S1.4. Frequencies (%) of best fitting person-specific models across behavioural groups (N=194).

Model	Overall	SB, n = 46	US, n = 57	AC, n = 52	TS, n = 39	p
Constant	15 (7.7%)	5 (11%)	3 (5.3%)	4 (7.7%)	3 (7.7%)	0.556
Linear	19 (9.8%)	4 (8.7%)	9 (16%)	3 (5.8%)	3 (7.7%)	
Quadratic	24 (12%)	5 (11%)	7 (12%)	6 (12%)	6 (15%)	
Cubic	31 (16%)	7 (15%)	8 (14%)	13 (25%)	3 (7.7%)	
Asymptotic	52 (27%)	16 (35%)	15 (26%)	9 (17%)	12 (31%)	
Logistic	53 (27%)	9 (20%)	15 (26%)	17 (33%)	12 (31%)	

Note. p-value based on Fisher's Exact Test for Count Data; SB: Sedentary behaviour; US: Unhealthy snacking; AC: Alcohol consumption; TS: Tobacco smoking.

Table S1.5. Distribution of RMSE across best-fitting person specific models (*N*=194).

Model	*N*	Median (*IQR*)	Range	*p*
Constant	15	0.30 (0.17, 0.39)	0.04 - 1.33	<0.001
Linear	19	0.38 (0.28, 0.52)	0.11 - 0.71	
Quadratic	24	0.36 (0.21, 0.55)	0.08 - 0.88	
Cubic	31	0.30 (0.20, 0.37)	0.08 - 0.57	
Asymptotic	52	0.23 (0.12, 0.41)	0.03 - 0.71	
Logistic	53	0.19 (0.11, 0.27)	0.02 - 0.96	

*Note***.** RMSE: Root-Mean-Square Error; IQR: Interquartile range; *p*-value based on Kruskal-Wallis rank sum test.

Table S1.6. Median (interquartile range) of missing value statistics across best fitting person-specific models (*N* =194).

Missing value statistic	Overall, *N* = 194	Constant, *n* = 15	Linear, *n* = 19	Quadratic, n = 24	Cubic, *n* = 31	Asymptotic, *n* = 52	Logistic, *n* = 53	*p*
Percentage Missing	7 (2, 35)	19 (0, 54)	21 (2, 52)	8 (2, 47)	7 (0, 26)	9 (2, 28)	5 (2, 35)	0.847
Longest missing gap (days)	3 (2, 15)	3 (0, 39)	3 (2, 19)	2 (2, 18)	2 (0, 10)	3 (2, 12)	3 (2, 7)	0.874

*Note***.** *p*-values based on Kruskal-Wallis rank sum test.

6.2.4 Person-specific sensitivity analyses

Two types of sensitivity analysis were conducted. First, person-specific models were fitted without usage of imputed SRBAI values. The frequencies of best fitting models remained relatively unchanged, with asymptotic and logistic models being the most common best fitting models. However, the asymptotic model was more frequently the best fitting model (*n* = 57) compared to the logistic (*n* = 43). See Table S1.7 for further details.

Table S1.7. Frequencies (%) of best fitting person-specific models without missing value imputation across behavioural groups (*N*=194).

Model	Overall	SB, *n* = 46	US, *n* = 57	AC, *n* = 52	TS, *n* = 39	*p*-value
Constant	17 (8.8%)	4 (7.7%)	5 (11%)	5 (8.8%)	3 (7.7%)	0.876
Linear	23 (12%)	3 (5.8%)	6 (13%)	10 (18%)	4 (10%)	
Quadratic	25 (13%)	7 (13%)	5 (11%)	7 (12%)	6 (15%)	
Cubic	27 (14%)	11 (21%)	7 (15%)	6 (11%)	3 (7.7%)	
Asymptotic	57 (29%)	13 (25%)	14 (30%)	16 (28%)	14 (36%)	
Logistic	45 (23%)	14 (27%)	9 (20%)	13 (23%)	9 (23%)	

Note. *p*-value based on Fisher's Exact Test for Count Data; SB: Sedentary behaviour; US: Unhealthy snacking; AC: Alcohol consumption; TS: Tobacco smoking.

Second, sensitivity analysis was conducted to assess the impact of updating if-then plans on day 48. On day 48 in total 59 participants (out of 194; 30 %) opted to update their if-then plan

(see Table S1.8). To test whether updating the if-then plan on day 48 had an impact on the habit strength trajectory, linear regression models predicting habit strength by time were conducted for two time windows – the week preceding day 48 and the week following day 48. Subsequently, the change in slope was calculated based on the difference in the linear parameter of the regression models for the two time windows. Results indicated (see Table S1.9.) that there was not a difference in the change in slope between participants who maintained the same if-then plan and those who updated their if-then plan.

Table S1.8. Frequencies (%) of how if-then plan strategies were changed on day 48 ($N = 59$)

Day 7 plan strategy	Day 48 plan strategy		
	Substitution	Inhibition	Discontinuation
Substitution	21 (35.6%)	10 (16.9%)	7 (11.9%)
Inhibition	5 (8.5%)	12 (20.3%)	2 (3.4%)
Discontinuation	1 (1.7%)	1 (1.7%)	0 (0%)

Note. Updating the if-then plan was optional. 59 out of 194 participants changed their plan on day 48.

Table S1.9. Median (interquartile range) of change in linear slope of habit strength from the week proceeding day 48 to the following week by if-then plan update status ($N = 163$).

	Overall ($N = 163$)	Plan unchanged ($n = 112$)	Plan updated ($n = 51$)	*p*
Change in slope	0.000 (-0.029, 0.026)	0.000 (-0.027, 0.026)	0.000 (-0.036, 0.030)	0.318

Note. *p*-value based on Kruskal-Wallis rank-sum test. Participants with > 0 observations for both time windows (days 41-48 and 48-55) were included in analysis.

6.2.5 Exploration of habit strength trajectories and to cue-behaviour performance

The SHRI and SRBAI have been successfully used to investigate within-person fluctuations in self-reported habit strength during habit formation, but not yet for habit decay. One may ask, therefore, whether it is plausible that individuals can reflect on their habit when they do not perform the behaviour at the occurrence of the cue. We explored this with the following additional analyses. To establish whether and to what extent the perception of habit strength reflects the performance of the target behaviour when encountering the cue, additional data visualizations were generated. This exploration is not a comprehensive assessment of the data. The purpose is to provide insights to how behaviour potentially influences the perception of habit in the context of trying to degrade a habit. This serves to inform about the validity of the present measurement of habit strength.

Methods. For this exploration, items from the end-of-day e-diary (days 8 to 91) questionnaire addressing cue-encounters and performance of the target behaviour in response to cue encounters were utilized. Cue-encounters were assessed daily with one single item that referenced the participant's self-selected cue "Have you experienced the (*cue*) situation you chose today?", with 3 answer options: 0) *no*, 1) *yes, once*, and 2) *yes, several times*. Subsequently if participants reported having encountered their cue, they were asked about performing their target behaviour with one single item, for example (for the tobacco smoking

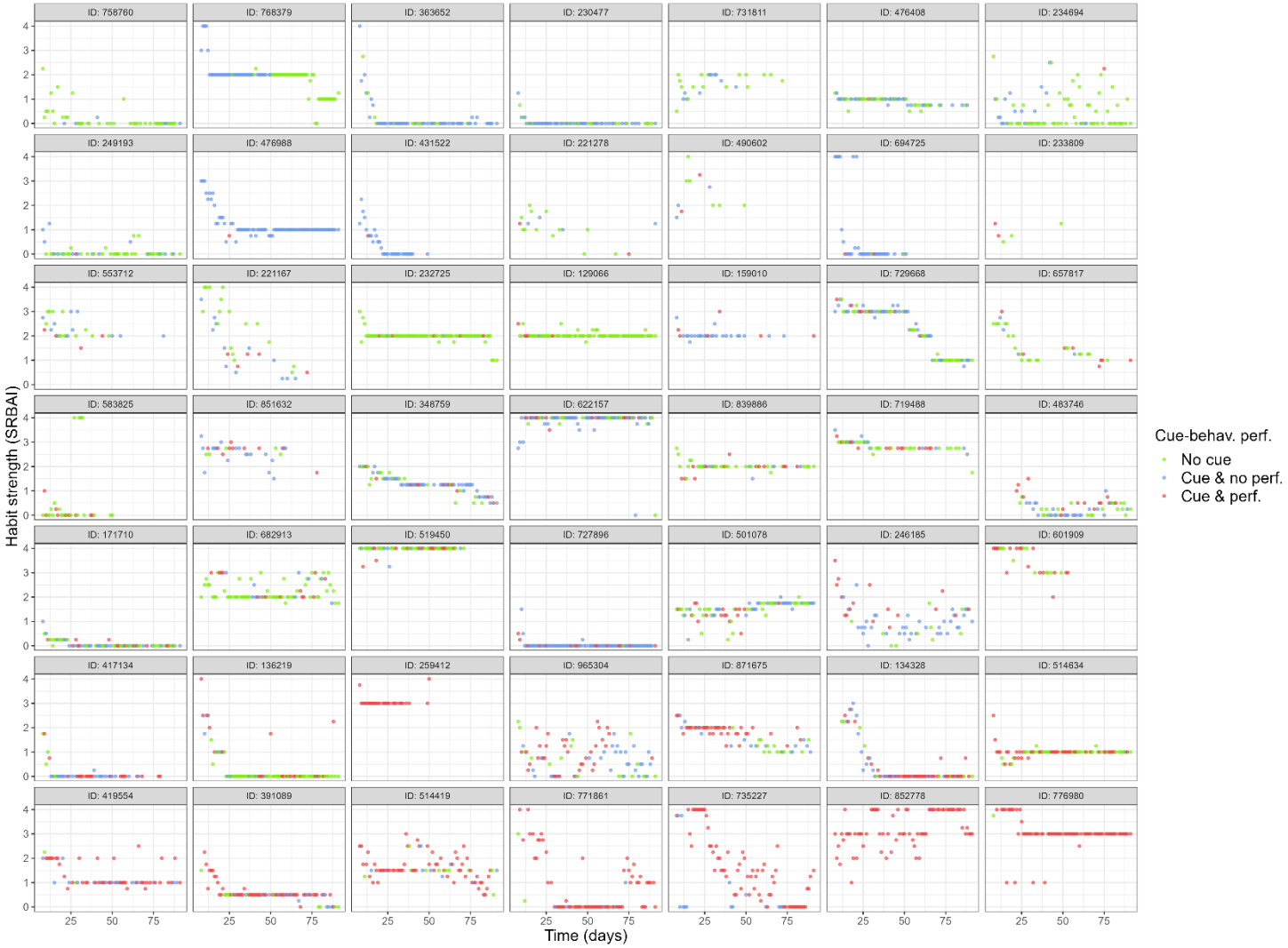
group) "*Did you smoke in the situation you selected (cue)?*". The response options for this latter item depended on the participant's response to the previous cue-encounters item. Specifically, if the participant reported encountering the cue once, the response options for the behavioural performance were 0) *no* and 1) *yes*. If the participant reported encountering the cue multiple times, the response options were 0) *no*, 1) *yes, sometimes* and 2) *yes, always.* The previously described items were added to the e-diary questionnaire approximately one month after the launch of study recruitment, and consequently these items were available for the full duration of study participation for 49 participants in total.

To facilitate interpretation of the present analysis, daily cue-encounters and cue-behaviour performance item responses were used to compute a 3-level categorical variable indicating whether 1) the cue had not been encountered, 2) the cue had been encountered and the behaviour was subsequently not performed, and 3) the cue had been encountered and the behaviour was subsequently performed at least sometimes. Subsequently, habit strength observations were plotted over time (observed values only for days 8 to 91). The 3-level categorical cue-behaviour performance variable was added to the plots to visualize how this potentially covaried with habit strength. This procedure was done with participant data where cue-encounters and cue-behaviour performance could be reported for the full time series (n = 49).

Results. The below Figure S1.3. panel plot displays 49 person-specific habit strength time series, where observations are colour coded based on whether the cue was not encountered on that day (green), the cue was encountered and the behaviour not performed (blue), or the cue was encountered and the behaviour was performed at least sometimes (red). The individual plots are ordered based on the number of days when the cue-behaviour was performed. Here, the first row contains time series where the cue-behaviour was performed on 0 to 1 days in total, whereas on the last row the cue-behaviour was performed on 43 to 72 days in total. The plots in Figure S1.3. indicate that the association between cue-behaviour performance and habit strength is idiosyncratic. Based on visual inspection, generalizations across participants cannot be made as to how habit strength may covary with cue-behaviour performance. Findings suggest habit strength is not merely a reflection of cue-behaviour performance or lack thereof. Importantly, trends are not evident that would suggest a difference in habit strength when the cue-behaviour is performed compared to when it is not performed.

Results show that for some participants, habit gradually decreases while the behaviour was relatively consistently not performed at cue encounters (e.g. 1st row, plots 2 & 3; 2nd row plots 2 & 3; 4th row plot 3). Other participants show limited change in habit strength while the behaviour was relatively consistently not performed at cue encounters (e.g. 3rd row, plot 4 & 5). Lastly, there were less visible associations between cue-behaviour performance and habit strength for some participants (e.g. 1st row, plot 7; 7th row, plot 6).

Figure S1.3. Panel plot of person-specifc habit strength trajectories and cue-behaviour performance ordered by performance frequency (n = 49).



Note. Cue-behaviour performance does not account for multiple cue encounters on the same day. SRBAI = Self-Report Behavioural Automaticity Index; Cue-behav. Perf = Cue-behaviour performance

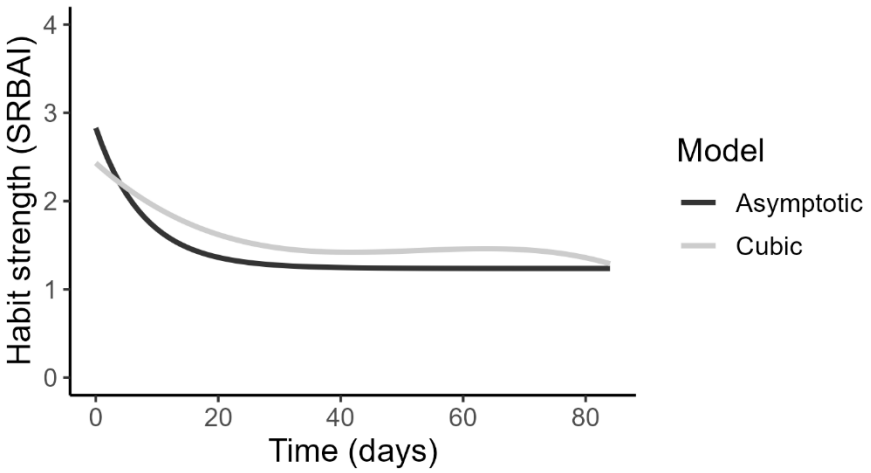
Discussion. Overall, the present explorative data visualization of habit strength and cue-behaviour performance provides initial support for the use of self-report habit strength in the context of habit degradation. The rationale for this conclusion lies in one key observation. Namely, findings show that habit strength (i.e. perceived automaticity) is distinct from cue-behaviour performance. Within the presented plots there are no instances where habit strength would merely reflect the cue-behaviour performance of that day. Without going into substantial interpretation of the plots, this indicates that it is feasible for an individual to distinguish between (non-)performance of habitual behaviour, and the strength of automaticity of the underlying habit. This underscores a key facet to validity, as contemporary definitions of habit denote the cognitive representation of the cue-behaviour association to be the key component of a habit, where habitual behaviour is a potential outcome of an underlying habit (Fleetwood, 2021; Gardner, 2015).

Establishing that habit strength and cue-behaviour performance are distinct within the context of degrading a habit is an essential first step for determining measurement validity of self-report habit strength. More research is needed to deepen our understanding of potential boundary conditions for when self-report habit strength can accurately be assessed while degrading a habit. For example, it is relevant to determine how irregular or infrequent cue encounters, and inconsistent responding to cue encounters (e.g. due to multiple daily cue encounters) may potentially influence the perception of automaticity. These latter cue-behaviour performance characteristics may provide insight into some of the unexplained variation observed in habit strength; however, such an investigation falls outside of the scope of the present paper. Person-specific data visualization combined with think-aloud qualitative methods may be a fruitful avenue for future intensive longitudinal research on habit degradation to further explore validity.

6.2.6 Group-level modelling

Multilevel modelling indicated the asymptotic model with random effects estimated for all parameters to have the best parsimonious fit, followed by the cubic model with all random effects estimated. The fixed effects of both these multilevel models were similar in shape as shown in Figure S1.4.

Figure S1.4. Plot of two-level asymptotic and cubic model fixed effects (N = 194).



Note: SRBAI = Self-Report Behavioural Automaticity Index.

6.2.7 Behavioural group differences

Using the asymptotic model, behavioural group differences were investigated by adding behavioural group random effects. Results indicated allowing for initial habit strength to vary by behavioural group improved model fit. Results also gave indication that allowing for asymptote to vary by behavioural group improved model fit, but not for the rate of change (see Table S1.10). Allowing for both initial habit strength and asymptote to vary by behavioural group (not displayed) did not improve model fit by any indices.

Using the cubic model, behavioural group differences were investigated by adding intercept by behavioural group main effects and interaction terms to the model. Results indicated adding a main effect (i.e. intercept) for each behavioural group improved model fit for sedentary behaviour and alcohol consumption groups (Table S10). See Table S1.11 for estimates of the cubic multilevel models with behavioural group main effects; here it can be seen that the intercept is significantly higher for the sedentary behaviour group and lower for the alcohol consumption group compared to the average intercept of the other behaviours combined. See Table S1.12 for estimates of the cubic multilevel models with interaction terms for the time parameters for each behavioural group; here it can be seen that the estimates of the interaction terms for the linear and polynomial time parameters are not significant as the confidence intervals include the value 0.

Table S1.10. Comparison of two- and three-level models predicting habit strength with different time parameters (N = 194).

Models	*df*	*AIC*	*BIC*	Deviance	$\Delta\chi^2$	Δdf	p(Δχ2)
Asymptotic							
M1: Between person random effects for *R0*, *ASYM*, *LRC* (two-level)	7	14898	14950	14884			
M1 + behavioural group random effect for *R0*	8	14841	14901	14825	58.915	1	<.001
M1 + behavioural group random effect for *ASYM*	8	14896	14956	14880	3.9729	1	0.046
M1 + behavioural group random effect for *LRC*	8	14900	14960	14884	0.0034	1	0.9532
Cubic							
M2: Between person random effects for β0, β1, β2, β3 (two-level)	15	15129	15241	15099			
M2 + Group main effect (sedentary behaviour)	16	15102	15222	15070	28.878	1	<.001
M2 + Group main effect (unhealthy snacking)	16	15128	15247	15096	3.3811	1	0.066
M2 + Group main effect (alcohol consumption)	16	15107	15226	15075	24.327	1	<.001
M2 + Group main effect (tobacco smoking)	16	15127	15247	15095	3.6235	1	0.057

Note. Asymptotic model parameters: *R0* = response on day 0, *ASYM* = asymptote, *LRC* = natural logarithm of rate constant; Cubic model parameters: β0 = Intercept, β1 = Linear time, β2 = Quadratic time, β3 = Cubic time; *BIC* = Bayesian Information Criterion; *AIC* = Akaike Information Criterion

Table S1.11. Multilevel cubic models with behavioural group main effects (N = 194).

	Fixed effects				RE
Parameters	Estimate	*SE*	*t*-value	95% *CI*	*SD*
Intercept (β0)	2.24	0.08	29.72	[2.09, 2.38]	0.91
Time (β1)	-3.03	0.26	-11.65	[-3.55, -2.52]	3.49
$Time^2$ (β2)	2.94	0.32	9.30	[2.32, 3.57]	4.17
$Time^3$ (β3)	-0.91	0.11	-8.22	[-1.13, -0.69]	1.43
Group (Sedentary behaviour)	0.82	0.15	5.63	[0.53, 1.11]	
Residual					0.39
Intercept (β0)	2.51	0.08	30.09	[2.35, 2.67]	0.98
Time (β1)	-3.03	0.26	-11.65	[-3.55, -2.52]	3.49
$Time^2$ (β2)	2.94	0.32	9.29	[2.32, 3.57]	4.17
$Time^3$ (β3)	-0.91	0.11	-8.21	[-1.13, -0.69]	1.43
Group (Unhealthy snacking)	-0.27	0.15	-1.86	[-0.56, 0.02]	
Residual					0.39
Intercept (β0)	2.62	0.08	33.75	[2.47, 2.78]	0.93
Time (β1)	-3.03	0.26	-11.65	[-3.55, -2.52]	3.49
$Time^2$ (β2)	2.94	0.32	9.29	[2.32, 3.57]	4.17
$Time^3$ (β3)	-0.91	0.11	-8.21	[-1.13, -0.69]	1.43
Group (Alcohol consumption)	-0.72	0.14	-5.12	[-1.00, -0.45]	
Residual					0.39
Intercept (β0)	2.37	0.08	29.94	[2.21, 2.52]	0.98
Time (β1)	-3.03	0.26	-11.65	[-3.55, -2.52]	3.49
$Time^2$ (β2)	2.94	0.32	9.29	[2.32, 3.57]	4.17
$Time^3$ (β3)	-0.91	0.11	-8.21	[-1.13, -0.69]	1.43
Group (Tobacco smoking)	0.32	0.17	1.93	[-0.01, 0.64]	
Residual					0.39

Note. Time is scaled to vary from 0 to 1.7.; Group interaction term is coded 0 or 1, where 1 refers to the specified behavioural group and 0 all other behavioural groups combined. RE: random effects; *CI*: confidence interval; Confidence intervals computed using Wald t-distribution with Satterthwaite approximation; *SD*: standard deviation.

Table S1.12. Fixed effect estimates [95% confidence interval] for multilevel cubic models with interaction terms for each behavioural group.

	Sedentary behaviour			Unhealthy snacking		
Parameters	M2a	M2b	M2c	M2a	M2b	M2c
Intercept	2.23 [2.08, 2.38]	2.22 [2.07, 2.37]	2.21 [2.06, 2.36]	2.52 [2.36, 2.69]	2.52 [2.35, 2.69]	2.53 [2.36, 2.69]
Time	-3.01 [-3.52, -2.49]	-2.96 [-3.48, -2.43]	-2.84 [-3.42, -2.25]	-3.06 [-3.58, -2.55]	-3.06 [-3.59, -2.52]	-3.20 [-3.81, -2.59]
$Time^2$	2.95 [2.32, 3.57]	2.92 [2.29, 3.55]	2.76 [2.05, 3.47]	2.94 [2.32, 3.57]	2.94 [2.31, 3.57]	3.14 [2.39, 3.88]
$Time^3$	-0.91 [-1.13, -0.69]	-0.91 [-1.13, -0.69]	-0.86 [-1.10, -0.61]	-0.91 [-1.13. -0.69]	-0.91 [-1.13, -0.69]	-0.98 [-1.24, -0.72]
Group	0.86 [0.57, 1.15]	0.90 [0.59, 1.21]	0.92 [0.61, 1.23]	-0.31 [-0.60, -0.01]	-0.30, [-0.61, 0.01]	-0.32 [-0.63, -0.01]
Group by time	-0.12 [-0.28, 0.04]	-0.32 [-0.82, 0.18]	-0.83 [-2.04, 0.37]	0.09 [-0.05, 0.24]	0.07 [-0.39, 0.54]	0.57 [-0.55, 1.70]
Group by $time^2$		0.10 [-0.14, 0.35]	0.79 [-0.68, 2.26]		0.01 [-0.21, 0.23]	-0.65 [-2.02, 0.72]
Group by $time^3$			-0.24 [-0.76, 0.27]			0.23 [-0.24, 0.71]
	Alcohol consumption			Tobacco smoking		
Parameters	M2a	M2b	M2c	M2a	M2b	M2c
Intercept	2.63 [2.48, 2.79]	2.64 [2.48, 2.79]	2.64 [2.49, 2.80]	2.36 [2.20, 2.52]	2.37 [2.21, 2.52]	2.36 [2.20, 2.52]
Time	-3.05 [-3.57, -2.54]	-3.08 [-3.61, -2.56]	-3.21 [-3.81, -2.61]	-3.01 [-3.53, -2.50]	-3.04 [-3.57, -2.52]	-2.91 [-3.48, -2.34]
$Time^2$	2.94 [2.32, 3.57]	2.96 [2.33, 3.58]	3.12 [2.39, 3.85]	2.94 [2.32, 3.57]	2.96 [2.33, 3.58]	2.78 [2.08, 3.48]
$Time^3$	-0.91 [-1.13, -0.69]	-0.91 [-1.13, -0.69]	-0.97 [-1.22, -0.71]	-0.91 [-1.13, -0.69]	-0.91 [-1.13, -0.69]	-0.85 [-1.09, -0.60]
Group	-0.75 [-1.04, -0.47]	-0.78 [-1.08, -0.48]	-0.79 [-1.10, -0.49]	0.36 [0.03, 0.69]	0.32 [-0.03, 0.67]	0.35 [0.00, 0.70]
Group by time	0.08 [-0.07, 0.23]	0.19 [-0.29, 0.67]	0.66 [-0.50, 1.81]	-0.10 [-0.27, 0.06]	0.06 [-0.48, 0.59]	-0.61 [-1.89, 0.67]
Group by $time^2$		-0.06 [-0.29, 0.17]	-0.67 [-2.08, 0.74]		-0.08 [-0.34, 0.18]	0.81 [-0.75, 2.37]
Group by $time^3$			0.22 [-0.27, 0.71]			-0.31 [-0.86, 0.23]

Note: N = 194; Dependent variable is Self-Report Behavioural Automaticity Index (score range 0-4); Time rescaled to 0 - 1.72 (i.e. 1 day increase equates to ca. 0.02 increase in rescaled time); Group term coded 0, 1, where 1 refers to the specified behavioural group and 0 all other behavioural groups combined. All models have between person random effects estimated for all parameters (not displayed); Confidence intervals calculated with Satterthwaite approximation; M2a: model with interaction for linear time by group; M2b: model with interaction for quadratic time by group; M2c: model with interaction for cubic time by group.

6.2.8 Group-level sensitivity analyses

Sensitivity analysis was conducted by rerunning the cubic multilevel models with behavioural group main effects without using missing value imputation, which confirmed previous results (see Table S1.13). Additionally, day 7 intention was added as a covariate to the cubic multilevel model (with imputed SRBAI values), which indicated intention to have a negligible effect despite displaying a significant interaction with the cubic time parameter (see Table S1.14 and Figure S1.5). The absence of an effect of day 7 intention on the habit degradation process is reasonable considering that intention strength varies over time (Conner & Norman, 2022).

Table S1.13. Multilevel cubic model predicting habit strength by time with main effect for behaviour group without missing value imputation (N = 194).

	Sedentary behaviour				Unhealthy snacking			
Parameters	Estimate	*SE*	95% *CI*	*p*	Estimate	*SE*	95% *CI*	*p*
Intercept	2.24	0.08	[2.10, 2.39]	<0.001	2.52	0.08	[2.35, 2.68]	<0.001
Time	-3.06	0.26	[-3.57, -2.55]	<0.001	-3.06	0.26	[-3.57, -2.55]	<0.001
$Time^2$	2.98	0.32	[2.36, 3.60]	<0.001	2.97	0.32	[2.36, 3.59]	<0.001
$Time^3$	-0.92	0.11	[-1.14, -0.71]	<0.001	-0.92	0.11	[-1.14, -0.71]	<0.001
Group	0.82	0.15	[0.53, 1.10]	<0.001	-0.27	0.14	[-0.55, 0.01]	0.061
	Alcohol consumption				Tobacco smoking			
Parameters	Estimate	*SE*	95% *CI*	*p*	Estimate	*SE*	95% *CI*	*p*
Intercept	2.63	0.08	[2.48, 2.78]	<0.001	2.37	0.08	[2.22, 2.52]	<0.001
Time	-3.06	0.26	[-3.57, -2.55]	<0.001	-3.06	0.26	[-3.57, -2.55]	<0.001
$Time^2$	2.97	0.32	[2.35, 3.59]	<0.001	2.97	0.32	[2.35, 3.59]	<0.001
$Time^3$	-0.92	0.11	[-1.14, -0.71]	<0.001	-0.92	0.11	[-1.14, -0.71]	<0.001
Group	-0.72	0.14	[-1.00, -0.45]	<0.001	0.33	0.16	[0.00, 0.65]	0.047

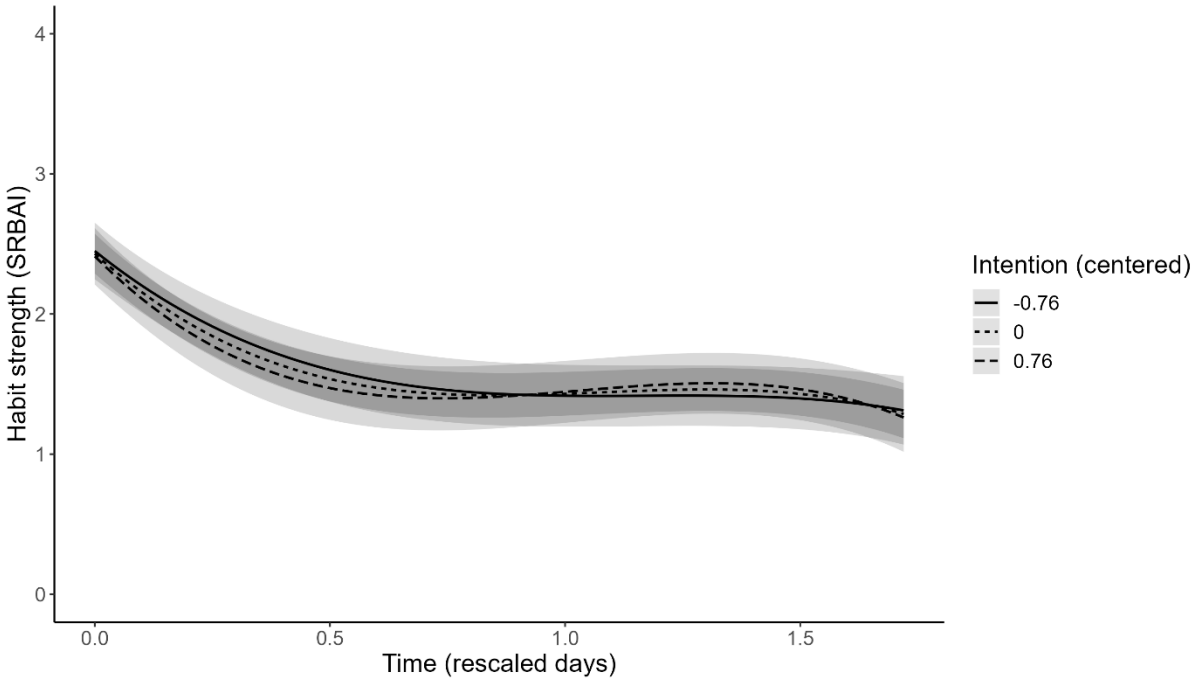
Note. CI: Confidence interval; Confidence intervals calculated with Satterthwaite approximation

Table S1.14. Multilevel cubic model predicting habit strength by time with main effect and interaction terms for day 7 intention (N = 194).

Parameters	Estimate	*SE*	*95% CI*	*p*
Intercept	2.43	0.07	[2.29, 2.57]	<.001
Time	-3.03	0.26	[-3.54, -2.52]	<.001
Time2	2.94	0.31	[2.33, 3.56]	<.001
Time3	-0.91	0.11	[-1.13, -0.70]	<.001
Intention	-0.02	0.10	[-0.21, 0.16]	0.797
Intention by time	-0.45	0.34	[-1.12, 0.23]	0.191
Intention by time2	0.82	0.41	[0.00, 1.63]	0.049
Intention by time3	-0.32	0.14	[-0.61, -0.04]	0.024

Note. Intention is grand mean centred; CI: Confidence interval; Confidence intervals calculated with Satterthwaite approximation

Figure S1.5. Multilevel cubic model plots with day 7 intention as covariate (N = 194).



Note. Intention is grand mean centred and displayed at the mean level (0) and 1 standard deviation below (-0.76) and above (0.76) the mean. Time (days 0 to 84) has been rescaled to vary from 0 to 1.72

7. Supplementary material II

This is the supplementary material that accompanies the article preprint (Manuscript II): Edgren, R., & Inauen, J. (2025). Determinants and strategies of habit degradation: An intensive longitudinal study. https://doi.org/10.31219/osf.io/2xzsw_v1

7.1 Measures

Perceived stress was measured with past day diary items adapted from the German Perceived Stress Scale (S. Cohen et al., 1983; Schneider et al., 2020) as follows: "*How often were you upset because something unexpected happened today"* and "*How often have you felt nervous or stressed today?*.

Next day intention (De Bruijn et al., 2012; Edgren et al., 2024) was measured with the items "*To what extent do you intend to reduce your* [target behaviour] *when you encounter the selected situation* [cue]?" and "*I plan to reduce my* [target behaviour] *tomorrow in my chosen situation* ([cue])".

7.2 Implementation intention qualitative analysis

The cues selected by participants on Day 7, and the implementation intentions created on Day 7 (and Day 48 updated implementation intentions) were analysed with a coding scheme developed from a previous similar coding scheme (Warner et al., 2022), the implementation intention taxonomy (Prestwich et al., 2015) and refined based on pretesting present procedures. Content of the present analysis that is novel (i.e. not from noted sources) is the evaluation of cue categories (for the self-selected cue and the if-component; sections I and IV of guidelines) into physical, social, emotion/cognition, and event/action contexts which was created when pilot testing these procedures. Also, coding of habit degradation strategy (section V of guidelines), mismatch between cue and if-component (section III-B), and intended outcome of implementation intentions (section III-C), are unique to the present coding scheme. Lastly, coding of the then-part response type (section VII) which is based on the noted taxonomy (Prestwich et al., 2015), was adapted to distinguish between behavioural responses that are intended to replace an old behaviour or not (VII-A & B), and whether the amount of the replacement behaviours is specified. Similarly, the response type reasoning was specified to distinguish between limit setting and directing attention (VII-C & D).

7.2.1 Procedure

All coding was completed using Microsoft Excel. Pretesting procedures was conducted with cues and implementation intentions from the sedentary behaviour and unhealthy snacking groups independently by two research assistants in duplicate, and guidelines revised based on disagreements that incurred. For the final coding scheme, a subsample of cues and implementation intentions ($N = 60$; 15 from each behavioural group) were coded in duplicate. Interrater agreement was high, suggesting the guidelines enable replicable coding. Gwet's coefficients were used to assess inter-rater agreement for nominal and ordinal variables, as these provide a stable and interpretable measure of agreement compared to Kappa statistics which problematically assume chance agreement (Loef et al., 2022; Tong et al., 2020). For nominal variables, which comprised approximately 86% of the dataset, Gwet's AC1 was 0.9198 (95% CI: 0.906–0.933, $p < 0.001$), indicating very high agreement (Landis & Koch, 1977). To account

for our imbalanced, and high-agreement dataset, we applied ordinal weighting to AC2 (Tran et al., 2020). The ordinal variables (i.e. specificity ratings; section 6 of below guidelines), representing about 7% of the dataset, yielded a Gwet's AC2 of 0.7792 (95% CI: 0.701–0.857, $p < 0.001$), reflecting substantial agreement, though slightly lower than AC1 due to the weighting applied for ordinal differences. Finally, for the ratio variables (i.e. coding number of if- and then- components; section 2D in below guidelines), the intraclass correlation coefficient was 0.911 (95% CI: 0.875–0.937), signifying excellent reliability (Koo & Li, 2016). The guidelines created for completing the qualitative analysis are subsequently presented.7.2.2 Coding scheme guidelines

7.2.2 Coding scheme guidelines

Introduction

This guide is designed to analyse the if-then plans (implementation intentions; II) which participants created during the HABIRUPT study from September 2022 to April 2023. In the HABIRUPT study, subjects were instructed to create an if-then plan to reduce or stop a self-selected habitual behaviour. To do this, they first chose a specific situation (cue) in which they would exhibit the behaviour and now want to change it. Then they could choose one of three strategies to create an individual implementation intention on how to reduce their habit. Here is an example of such an implementation intention to reduce sedentary behaviour: "When I work in the office, I will work standing up for 30 minutes."

With the help of this guide, the following aspects of cues and if-then plans are to be evaluated:

- I. Cue category (based on self-defined cue)
- II. Correctness of the implementation intention
  - a. Multiple IIs created (within same session)
  - b. Validity (Adherence to the instruction)
  - c. Usage of words "If" and "then"
  - d. Number of II components
    - i. Number of if-components
    - ii. Number of then-components
- III. Basic characteristics
  - a. II worded as negation
  - b. Potential mismatch between cue and if-component
  - c. Intended outcome of II
- IV. Categorize cue category in the implementation intention if-part
- V. Habit degradation strategy
- VI. Code the specificity of the implementation intention
  - a. Specificity of if-component
  - b. Specificity of then-component
- VII. Then-component response type
  - a. New behaviour
  - b. Replace behaviour
    - i. Replace behaviour: Amount
  - c. Reasoning: Setting limits
  - d. Reasoning: Directing attention
  - e. Affect regulation
  - f. Self-efficacy boosting
  - g. Self-affirmation

I. Cue category (based on self-defined cue)
Determine cue context category (physical context, social context, emotion/physical sensation/cognition, event/action, other) **by only referring to the self-selected cue** (not what is stated in the II).

The first step is to evaluate what type of cue it is. This may be one or more of the following categories. Below you will find a table with the 5 categories and examples from sedentary behaviour and unhealthy snacking. Since these examples are sufficient to understand the task, examples of alcohol consumption and smoking are not displayed. The lists of examples are not exhaustive.
1. Please read all the categories and the examples below carefully.

2. Then decide for each cue which cue categories you can find in it and enter **1** for the columns that occur, **0** for the columns that do not occur.

		EXAMPLES	
	CATEGORY	Sedentary behaviour	Unhealthy snacking
A	**Physical context**		
	Cues related to the physical environment or objects	Train, car, desk, office chair, lecture hall, home	See snacks, Kitchen, Fridge, Shop
B	**Social context**		
	Cues relating to the person(s) present or their absence	Lunch in a group, meeting friends	being alone, being in the presence of someone eating snacks
C	**Emotion / Cognition**		
	Cues related to emotions, physical sensations or thoughts	Tired, being stressed, desire to relax, wanting to sit down, ruminating, feeling relaxed	Hunger, thirst, sadness, stress, craving or desire for something sweet, to feel lonely, negative thoughts.
D	**Event / action**		
	Cues such as actions, routines, events that are about to start, are taking place or have already taken place. Also temporal information such as times of day, frequencies	Breakfast/ lunch/ dinner, work, relaxing, watch TV, take a break, every Monday, once a week	Take a break, after lunch, at 13:00, in the morning
E	**Other**		
	Cues that do not fit into any of the above categories		

Noteworthy examples:

Cue “Stressful day”: code as emotion & event (→ code category C & D as **1)**

a. Stress refers to emotion, and the culmination of that days events serves as relevant event based context

Cue “reward after dinner”: code as emotion & event (→ code category C & D as **1)**

b. Here, reward can be understood as an internal anticipation/expectation. After dinner is an event

II. Correctness of the implementation intention

A) Multiple IIs created (within same session)

- If the II includes multiple separate plans, code as **1**. Otherwise code as **0**
  For example:
  «If I arrive at the office, then I will work on the standing desk. If I work at home, then I will find another solution» → code as **1**.
  «If I am tired, then I will drink a glass of water» → code as **0**

B) Validity (Adherence to the instruction)

A valid implementation intention contains one cue, which is linked to one response. This plan should function as a clear instruction so that following it leads to a reduction or avoidance of the target behaviour (sitting, unhealthy snacking, smoking, or alcohol consumption). This validity check verifies that participants have followed the instructions.

A valid response must...

- ...function as a clear instruction so that following it leads to reduction or avoidance of the habitual behaviour.

A valid plan must...

- ...contain a valid cue and a valid response and link them together.

1. Decide for each plan whether the conditions are fulfilled and enter a 1 for a valid plan and a 0 if you think the conditions are not met.
2. If there is any ambiguity or uncertainty, please leave a comment.

Example of a valid plan: "When I'm on my afternoon coffee break and I'm craving something sweet, I'll eat an apple."

à Here, the desire for something sweet during the afternoon coffee break is the cue and the reaction is to eat an apple. This can prevent snacking on something unhealthy. Thus, this plan is valid**. = 1**

Example of an invalid plan: "When I come home in the evening, I usually drink a beer. I'll stop doing that in the future and drink water."

à The cue was mentioned here (coming home in the evening), but it is not explicitly linked to the response (drinking water). Thus, this is not a valid plan. **= 0**

Example of an invalid plan: "When I get up in the morning, I smoke."

à No plan is included here that is aimed at reducing or preventing the habitual behaviour that should be tried to change. Thus, this plan is not valid. **= 0**

C) Usage of words “If” and “then”

The next step is to check whether the plans have been written down in the correct format.

1. Decide for each plan whether the two conditions are fulfilled and enter the points (1 or 0) in the corresponding fields of the Excel table.
2. If there is a second sub-sentence with a preparatory action, score this 1 in the appropriate column. If this is not the case, give 0 points.
3. In case of uncertainty, enter a short note as a comment in the Excel spreadsheet.

The first part of the sentence (the cue) should begin with "If".

- Sentence begins with the word "If"à 1 point
- Sentence begins with a word other than "If"à 0 points

The second part of the sentence (the chosen behaviour) should begin with "Then".

- Second part of the sentence begins with the word "Then"à 1 point
- Second part of sentence begins with a word other than "Then"à 0 points

Caution: Some plans contain a preparatory action or a second sub-sentence with additional information. This is not written in if-then format and does not need to be evaluated. Example: "When I come to work tomorrow, I will work at the standing desk for one hour. For that, I'll move the desk upstairs tonight." à Here, the second sentence serves as a preparatory action.

D) Number of II components

The task here is to decide whether the plans contain an appropriate amount of information. According to the instruction, the participants should choose one situation/cue (if-component) and link it to one behaviour/solution (then-component).

For each plan decide:

i. **the number of if-components** (cues) that are present and enter the corresponding number.

ii. **the number of then components** (behaviours/solutions) that are present and enter the corresponding number

For plans that do not include a cue or planned behaviour to reduce or avoid the habitual behaviour, enter 0 accordingly.

If you are unsure, please add a short comment to the Excel spreadsheet.

Example 1: one cue and one behaviour/solution (simple case)

For example, a plan with one cue and one behaviour/solution would be:

"If it's coffee break in the afternoon, then I will eat an apple instead of an unhealthy snack."

à Here the [afternoon coffee break] is the cue = **1 point**

à [Eat apple] would be the behaviour/solution = **1 point**

Example 2: one cue and one behaviour/one solution (complex case)

A plan with one cue that seems a little more complex would be the following:

"After I put my daughter to bed and walk into the living room, I grab my yoga mat and do 10 minutes of fitness and 10 minutes of stretching."

à Here [putting daughter to bed and entering the living room] is the cue. Why doesn't that count as a multiple cue? It is a sequence of actions which is linked to 'and' and can therefore occur in this exact way and cue a habit. = **1 point**

à Here [grab the yoga mat, do 10min of fitness and 10min of stretching exercises] is also a sequence of actions which is linked to 'and' and can thus be counted as a behaviour/resolution. = **1 point**

Example 3: several cues and one behaviour/one solution (simple case)
An example with multiple cues would be the following:
"If I'm on my phone on social media or watching TV, then I will set myself a limit of one hour."

à There are two cues here, using social media on the mobile phone or watching TV. Objects linked with an 'or' indicates two cues. **= 2 points**

à The behaviour/solution here is clear [set yourself a limit of 1h]. **= 1 point**

Example 4: one cue and multiple behaviours/solutions (complex case)
An example with one cue and multiple behaviours/solutions:
"If I'm sitting on the sofa and watching TV, I'll set a 50 min alarm then I'll get up and do something else."

à Here [sitting on the sofa and watching TV] is the cue. Since the two actions are linked with an 'and' and can take place at the same time (represent a context), they count as one cue. **= 1 point**

à Less clear here is the behaviour/solution: [set an alarm] and [get up and do something else] are linked to a 'then'. However, this second subsentence contains a later cue [the alarm], which then triggers the second action (once the alarm goes off).
Thus, they represent a temporally staggered sequence of actions and are scored as two behaviours/solutions. = **2 points**

III. Basic characteristics

A) II worded as negation

- If the II instructs to **not** engage with the target behaviour without providing an alternative plan of action code as **1**. Otherwise code as **0**
  For example:
  «If I take a break, then I will l not smoke» → code as **1**
  «If I get on the bus, then I will not sit down and instead remain standing» → code as **0**

B) Potential mismatch between cue and if-component

- If the specified cue and if-component of the II are not congruent, code as **1.** Otherwise code as **0**

  For example:

  Cue: “Antsy about unusual situation”

  II: “If I occasionally have a craving for sweets, I will drink a glass of water.”

  → code as **1.** Here “feeling antsy about unusual situation” is not referred to in the II, and as such there is a mismatch.

  **

  Cue: “TV in the evening”

  II: “If I get off work, I will either go to the gym or alternately walk”

  → code as **1.** TV is not noted in the II, hence there is a mismatch. It is important to not interpret the plan beyond what is written (here it could be assumed that the person would normally go home and watch TV after work, but this assumption has a weak basis).

**

Cue: Teaching

II: If I get to school tomorrow morning, I will remove my chair away from my workstation.

→ code as **0.** While "teaching" is not mentioned in the II, it can reliably be assumed to take place at school (work place) without interpreting beyond what is written.

C) Intended outcome of II

- If the II has the intended outcome of completely avoiding performance of the target behaviour in response to encountering the cue, code as **avoid**
- If the II has the intended outcome of reducing performance of the target behaviour (but not completely avoiding it), code as **reduce**
- If the II intended outcome in terms of avoiding or reducing the target behaviour is unclear, code as **unclear**

For example:
"If I drink my morning coffee, then I will not smoke" → code as **avoid**

- Here the plan's intended outcome is that no smoking will take place while drinking coffee

"If I get to school tomorrow morning, I will remove my chair away from my workstation." → code as **avoid**

- Here, the participant intends to avoid sitting by removing the chair from their office. While it may seem unlikely that this in practice would work, this is what can be inferred as the intended outcome.

"If I work at the office, then I will work standing for 1h" → code as **reduce**

- Here the plan's intended outcome is that sedentary behaviour will take place 1h less

"If I come into my office I will stand at the standing desk to work." → code as **unclear**

- Here, based on how the II is written, it is unclear if the intended outcome is to work standing and completely avoid sitting, or to reduce sitting.

"There is no if then" → code as **unclear**

- Here, the II is poorly formulated and does not contain the necessary information to interpret the intended outcome.

"If I am dissatisfied, then think about what my goal is." → code as **unclear**

- Based on following goal, we cannot infer whether this intends to reduce or avoid target behaviour.

"If I get home tired, then I will exercise for 20 minutes" (cue: being tired) → code as **unclear**

- It remains unclear whether exercising effectively avoids or reduces sedentary behaviour in response to this cue. Here, we should avoid interpreting the plan beyond what is written.

IV. Categorize cue category in the implementation intention if-part
The following step is to evaluate what the cue category is that is stated in the if-part of the plan. This may be one or more of the following categories. This analysis serves to inform subsequent if-component specificity coding (see section VI-A.). Below [removed to shorten document; same table as displayed in section I. of Coding scheme guidelines] you will find a table with the 5 categories and examples of the respective behaviours (sedentary behaviour and unhealthy snacking). Since these examples are sufficient to understand the task, examples of alcohol consumption and smoking have been omitted. The lists of examples are not exhaustive.

1. Please read all the categories and the examples below carefully.
2. Then decide for each plan which cue(s) you can find in it and enter 1 for the columns that occur, 0 for the columns that do not occur.
3. If you are unsure, please add a short comment to the Excel spreadsheet.

Example of one category:

"When I get ready for bed, then I put the chair in the entrance."
à Here, 'got ready for bed' would be considered routine (D).

Examples of multiple categories:
"If I have a sweet tooth in the evening and want to search the kitchen, I will go and brush my teeth."
à Here, 'in the evening' would be evaluated as a temporal context (D) and 'desire for sweets' as a physical sensation (C).

"If I wake up at 03.00 and crave chocolate, then first of all I continue to sleep without going straight down."
à Here, 'at 3.00' represents a temporal context (D) and 'craving chocolate' a physical sensation (C).

"After I put my daughter to bed and walk into the living room, I grab my yoga mat and do 10 minutes of fitness and 10 minutes of stretching."
à Here one finds a social context (B) in [daughter], a routine or action that has taken place (D) in [put daughter to bed] and also a physical context (A) in [living room].

Category of first cue in if-part of plan
In addition to the categorization of cues that has just been completed, it is also to be coded which category the cue belongs to, which comes first. This is clear for plans with one cue.
In plans that contain several cue categories, the category that is at the beginning of the sentence or chain of actions should be noted. That is, the element that primarily triggers the habit.
For this categorization, please enter the category designation (A, B, C, D or E) in the corresponding column.
Example: "If in the evening I have a craving for sweets and want to search the kitchen, I will go brush my teeth."
→ in the evening comes first here (= temporal context D).

V. Habit degradation strategy
The following step is to evaluate the plans according to which habit degradation strategy they correspond to. The three strategies available for selection are explained below.

1. Decide for each plan which strategy it follows and enter the strategy in the corresponding column.
2. For plans in which no strategy or planned behaviour to reduce/prevent the habitual behaviour is evident, enter the letters NA.
3. Check whether the strategy selected by the participants (in "Strategy" column) matches the plan actually formulated and enter a 1 in the "Congruence" column if it is correct, otherwise a 0.
4. In some cases, it is not clear which strategy is being pursued with the plan. If you are not sure, take the strategy that comes closest to the planned behaviour. If you are unsure, please add a comment.

- **Substitution**: aims to replace the habitual behaviour with another one that is performed when the cue occurs. This should intend to replace the existing habit with a new habit.
    - In unhealthy snacking behaviour for example, a healthier snack alternative can be consumed.

  Example: "If I crave something sweet occasionally, I will drink a glass of water".
    - For sedentary behaviour, an example would be to spend at least part of the time that one normally sits more actively (e.g. standing up).

  Example: "If I study on my laptop or use other electronic devices for leisure or learning, I will spend 120 minutes a day of it standing."

- **Inhibition**: aims to suppress the impulse to perform the habitual behaviour and thus not perform the behaviour when the cue occurs. This is therefore about self-regulation in the moment of encountering the cue, with the aim of avoiding/reducing the behaviour.
    - With unhealthy snacking, for example, this can be to remember what limits you have set for yourself.

  Example: "When I want to eat snacks, I first think about the allowed number of snacks per day (1) and keep this rule."
    - For sedentary behaviour, you could also think about the health benefits of sitting less.

  Example: "When I get on the tram, I will think about how many calories I will burn standing up."
    - **Note:** Distinguishing between inhibition and replacement for sedentary behaviour should be done based on the exact wording of the plan. For example:
        - "…then I will not sit" should be coded as inhibition (plan is to avoid sitting down
        - "…then I will stand" should be coded as replace (plan is to stand instead of sitting down).
- **Avoid/Discontinuation**: aims to prevent encountering the cue.
    - For unhealthy snacking, for example, this could be to stop buying unhealthy snacks.

  Example: "When I go shopping, I will steer clear of the confectionery section."
    - For sedentary behaviour, this could be setting up the workstation so that you cannot sit down directly.

  Example: "When I have finished working I will pull up the desk and put away the office chair."

Note: Some cues cannot be avoided (for example "be done with work in the evening"). In such cases, replacement action or inhibition is more appropriate.

Example Strategy not clearly evident:
"If I plan and cook the main meals well, then I have less craving for things in between."
→ This plan is not worded correctly and is therefore more difficult to evaluate. [less craving for things in between] is closest to the avoid strategy, since the plan is to prevent craving (the cue) by planning and cooking the main meals.

VI. Code specificity of the implementation intention
The next part of the analysis is about how specific the plans are formulated. For this purpose, first the if-component and then the then-component (behaviour/solution) are coded according to specificity (1 = unspecific / 2 = moderately specific / 3 = very specific).
From experience we know that this part of the analysis is the most demanding. Please pay close attention when completing this step.

→ Enter the specificity evaluation in the appropriate column:
- 1 for unspecific
- 2 for moderately specific
- 3 for very specific
- NA for invalid plans, that do not contain a cue

→ If you are unsure, enter a short note as a comment in the Excel spreadsheet.

A) Specificity of if-component

Examples for each category are listed below.

	A: Physical Context
Unspecific (1)	- no precise indication of which place or object is meant ("outside", "inside", "somewhere", "electronic devices")
Moderately specific (2)	- several places/objects linked with 'or' or 'and' ("on the mobile or in front of the TV", "at home and in the office") EXCEPT: if both are unspecific, then rate as unspecific o E.g., “outside and inside” - formulated as an example ("for example in the office") - More specific environment ("at work", “in a shop”)
Very specific (3)	- specific naming of a room ("living room", “in my office”) or an object ("fridge", "in front of the TV") - specific place near the person ("in the park", "in the gym") - Animals ("with my dog")

	B: Social Context
Unspecific (1)	- general or inaccurate description of the social context ("not alone", "with someone")
Moderately specific (2)	- unspecific indication of the social context ("with a friend", “with friends”, "with relatives", "maybe with Bob", "if my husband has time”, “with him") - specific person but formulated as an example ("for example, with my daughter") - specific persons linked with an 'or' ("with one of my sisters or my friend Anke") EXCEPT: if both are unspecific, then rate as unspecific
Very specific (3)	- a specific person ("my daughter", "partner", " alone ") or group of people ("when I have dinner with my children") - different persons linked with an 'and' ("Sarah and John")

	C: Emotion / physical sensation
Unspecific (1)	- inaccurate description of an inner state ("when I feel like it")
Moderately specific (2)	- several emotional states linked with an 'or' ("when I am stressed or tired") EXCEPT: if both are unspecific, then rate as unspecific - inaccurate description of a feeling state ("when I don't feel well") which could represent several possible emotional states (tired, sad, insecure, sick...)
Very specific (3)	- Precise description of a feeling state or sensation ("being stressed", "desire for something sweet") - additional degree of strength of the sensation / feeling ("strong craving for something sweet")

	D: Event / Action
Unspecific (1)	- imprecise description of the temporal context ("during the holidays", "when I have time") - Frequency only ("three times a week", "often")
Moderately specific (2)	- either a time of day or a day of the week ("at 8:00 a.m.", "Tuesdays", "daily") - the weekend ("on the weekend") - different times linked with 'or' or 'and' or a time span ("on Wednesdays or Thursdays", "between 8:00 and 12:00", "in the afternoon") - formulated as an example ("for example on Saturday") - Description of a past, ongoing or following routine without time/day of the week/frequency ("when I brushed my teeth", "while I watch the news", "before I go to lunch").
Very specific (3)	- Time of day and day of the week ("every Saturday at 20:00") - exact moment ("in the evening before going to bed", "before I go home after work") - exact moment which is linked to routines does not need specification of time or day ("after dinner", "during breakfast") - exact description of the past, ongoing or following routine or action with time/day of the week/frequency ("every Monday after lunch", "when I drive to work in the morning", "before I get ready for bed in the evening", “when I brush my teeth in the evening”).

Note:
As shown in section “IV. Categorize cue category in the plan if-part”, cues of several categories may occur. In these cases, the specificity should be coded for all occurring categories in the corresponding column provided.

B) Specificity of then-component
The last step is the specificity coding of the planned action.

→ Enter the specificity evaluation in the appropriate column:
- **1** for unspecific
- **2** for moderately specific
- **3** for very specific
- **NA** for invalid plans, that do not contain a solution/behaviour

→ If you are unsure, enter a short note as a comment in the Excel spreadsheet.

Unspecific (1):
- no information of the planned action ("then I do something else", "nothing", "then I distract myself")

Moderately specific (2):
- broad description of the planned action ("then I do sport", “then I will train”, "then I think of the disadvantages of long sedentary behaviour", “then I will build a standing desk”)
- several actions linked with an 'or' ("then I eat fruit or drink water") EXCEPT: if both are unspecific, then rate as unspecific
- several actions linked with an 'and' ("then I do push-ups and stretching") EXCEPT: if both are unspecific, then rate as unspecific
- planned action formulated as an example ("then I will go to the gym, for example")
- concrete action without specifying the duration ("then I'll go for a walk)

Very specific (3):
- Concrete plan of action with an indication of duration ("then I stand for an hour") or quantity ("then I eat an apple", "then I throw away all the snacks I still have at home")
- concrete action plan to avoid the cue needs no indication of duration ("then I raise the standing desk")
- concrete actions linked with an 'and' ("then I eat an apple and drink a glass of water")
- specific action or thought process ("then I think about how many calories I will burn standing up")

Example of NA (invalid plan without solution/behaviour):
"I usually drink too much in the evening" → This plan does not contain a solution/behaviour and is therefore assigned NA (not applicable).

VII. Then-component response type

The following 8 items to be coded fall under the same umbrella, where the purpose is to identify with more detail **how** the then-component of the II attempts to change the response to encountering the cue. Note, that interpretation may require considering what the specified cue is.

If one of the following response types is present in the II, code as **1**. If a response type is not present, code as **0**. Please note, that an II may include several response types (and thus be coded as 1 on multiple items).

In general, when coding II for sedentary behaviour focus on what is explicitly stated in the plan. Do not consider what is implicitly implied by enacting the plan.

A) New behaviour

- Code as **1** if the II facilitates a new behaviour, that does not attempt to replace the existing habitual response. If the plan does not facilitate a new behaviour, code as **0**.
- This item needs to be evaluated in light of the specified cue. This response type primarily suites II's where the intention is to avoid encountering the cue in the future or the ability to respond habitually when encountering the cue. These response types often do not need to be continuously repeated, but this is not always the case (see example 2 below).
- II Example 1: If I get to the office, I will remove the office chair. → code as **1**
    - Removing the office chair is a new response that does not try to replace an existing habitual response. Removing the chair only has to be done once. This II intends to avoid being able to sit when encountering the cue "working at desk". Do not consider what is implicitly implied by enacting the plan. Performing this plan would imply replacing sitting with standing, but this should not be taken into account.
- II Example 2: If I go shopping tomorrow, I will not take sweets home. → code as **1**
    - The cue for this II is "Sweets in the cupboard". Hence, the II implies that the person wants to avoid having sweets at home, which will limit their ability to habitually eat sweets. The II does not try to replace the existing habitual response.

B) Replace behaviour

- Code as **1** if the II facilitates replacing an old response with a new response. The new response should be intended to be done repeatedly when encountering the cue. Code as **0** if the II does not facilitate replacing old behaviour.
- This response type primarily suites II's were the intention is to replace the target behaviour with a new favourable response.
- II Example 1: If I get tired at home, then I will exercise for 20 minutes. → code as **1**
    - The II intends to replace being sedentary with exercise, which needs to be repeated each time the cue "being tired" is encountered.
- II Example 2: If I watch a movie, then I start it on the stationary bike or on the gym mat. → code as **1**
    - The II intends to replace sitting with a more active way of watching a movie
- II Example 3: If I take a bus & tram ride, I will consciously remain standing for the ride time. → code as **1**
    - In this II, the person intends to inhibit sitting down, while also explicitly stating to replace this with "remaining standing", and as such replaces sitting with standing.

i) Replace behaviour: Amount

- Code this item if the II plan was coded as **1** for the previous Replace behaviour item. If the previous Replace behaviour item was coded as **0**, leave this item **blank.**
- If the II contains an indication of the amount (in time or units) that the replacement behaviour will be done, code as **1**. If the II does not state the planned amount, code as **0**.
- In the above Example 1, this should be coded as **1** (duration stated)
- In the above Example 2, this should be coded as **0** (duration not stated)
- In the above Example 3, this should be coded as **1** (duration stated in terms of "ride time")
- II Example 4: If I get a craving for something sweet, then I will a glass of water → code as **1**
    - Duration is stated in terms of units (***a glass*** of water).

C) Reasoning: Setting limits

- Code as **1** if the II facilitates inhibiting the target behaviour by referring to limits that the person has set themselves. The limit should refer to the **maximum acceptable amount of performing the target behaviour (which the person has set out to reduce)**. This may be expressed as not allowing consumption in certain situations (see example 4). If the II does not facilitate inhibition by setting limits, code as **0.**
- II Example 1: If I am sitting on the sofa watching TV I set a 50 min alarm then I will get up and do something else. → code as **1**
    - In this II the person has set a limit of 50min for sitting on the sofa
- II Example 2: If I have coffee after noon, I will skip the sweet snack as I only want to have Max 2x snacks a day. → code as **1**
    - Here the person gives set limits as the reasoning for not eating sweets during their afternoon coffee.
- Example 3: If I am in the car then I will remember my cigarette limit and no longer smoke in the car. → code as **1**
    - Here the II specifies a limit, although the exact number of this limit is not disclosed
- Example 4: If I sit down for dinner, then I won't drink beer. / If I'm lonely, then I won't look for distraction in intoxication. → code as **1**
    - The participant has set a limit (0) of beer with dinner / when lonely
    - Note that these examples are negations (participant telling themselves what not to do), and are not phrased as **reminders** of what not to do (e.g. then I will remind myself not to drink, which would be directing attention – see item below).

D) Reasoning: Directing attention

- Code as **1** if the II facilitates inhibiting the target behaviour by directing attention to alternative thoughts, goals, emotions, ongoing actions or something in the physical environment. Code as **0** if the II does not attempt to direct attention.
- This may also take the form of a statement / attitude that should be remembered when the cue is encountered, which may be stated as “I will remind myself that…”.
- Example 1: If I want a desert after lunch, then I will think that I am full. → code as **1**
    - Here attention is directed towards the thought of being satiated after eating
- Example 2: If I am dissatisfied, then think about what I have already achieved and what my goal is. → code as **1**
    - Here attention is directed towards personal goals. (Additionally this targets self-efficacy with “what I have already achieved”; see subsequent category).
- Example 3: If I'm in the car I'll remember to enjoy snacks with all my senses. → code as **1**
    - Here attention is directed towards savouring the moment, with the intention of limiting the amount consumed in this moment.
- Example 4: If I want to run towards the balcony, then I remember my plan and go to the kitchen and wake up a little bit first → code as **1**
    - Here attention is drawn to the plan, which is to postpone the first cigarette of the day (cue: The 1st cigarette right after getting up). This plan additionally facilitates to replace the behaviour (go to the kitchen; see previous category).
- Example 5: If I meet with friends, before I drink alcohol, I will again think through my positive thoughts about why it is better not to drink. → code as **1**
    - Here attention is directed to positive thoughts that provide reasoning why not to drink. Here “positive thoughts”, should also be coded as affect regulation (see below category)

E) Affect regulation

- Code as **1** if the II facilitates regulating affect/emotions. Code as **0** if the II does not attempt to regulate affect/emotion.
- Example 1: If I have stress (job, relationship, with kids), I will breathe calmly and mindfully and drink something. → code as **1**
    - Here, breathing calmly and mindfully are intended to regulate stress
- Example 2: If I am anxious, then I will look it bravely in the eye and accept it. → code as **1**
    - Here accepting feeling anxious is an attempt to regulate this state

F) Self-efficacy boosting

- Code as **1** if the II facilitates the desired response by boosting self-efficacy / enhancing the perception of capability to pursue the goal. Code as **0** if the II does not attempt to boost self-efficacy.
- Example: If I am dissatisfied, then think about what I have already achieved and what my goal is. → code as **1**
    - Here "what I have already achieved" facilitates enhancing the perception of capability to pursue goal

G) Self-affirmation

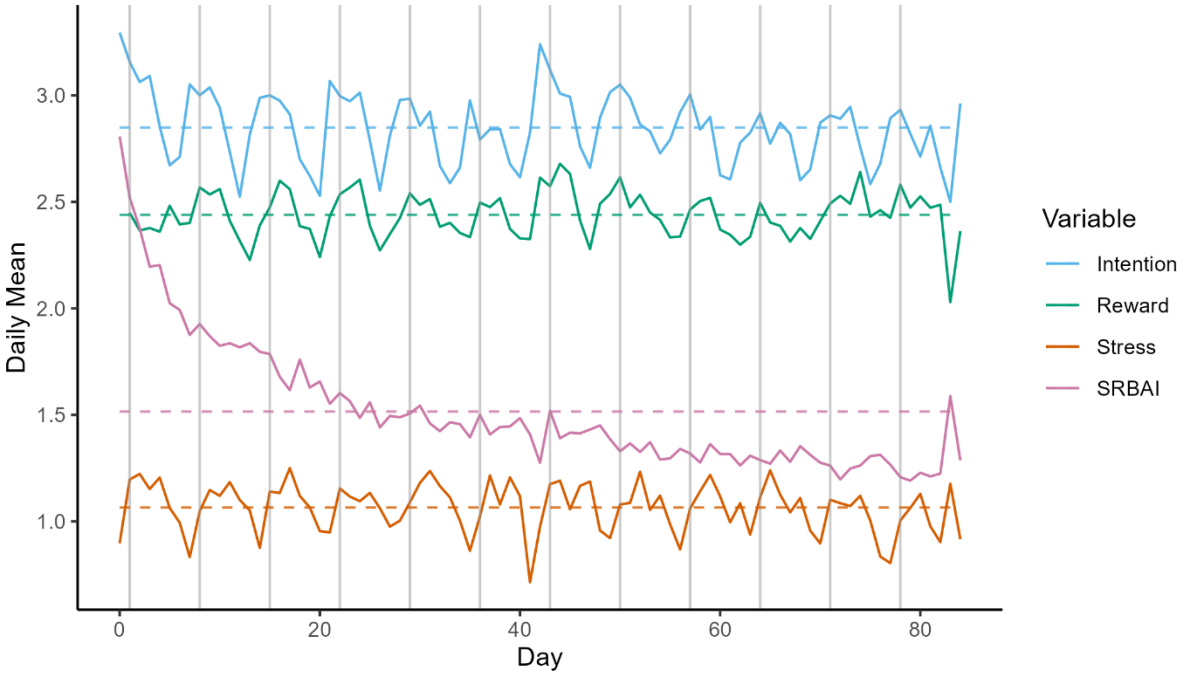
- Code as **1** if the II incorporates affirming oneself into the then-component. Code as **0** if the II does not incorporate affirming oneself.
- Example: If I feel anxious, then I will think about the things I value about myself. → code as **1**
    - Here the then-component of the plan links to concepts about the self in a positive light

7.3 Results

7.3.1 Descriptive visualizations of time varying variables

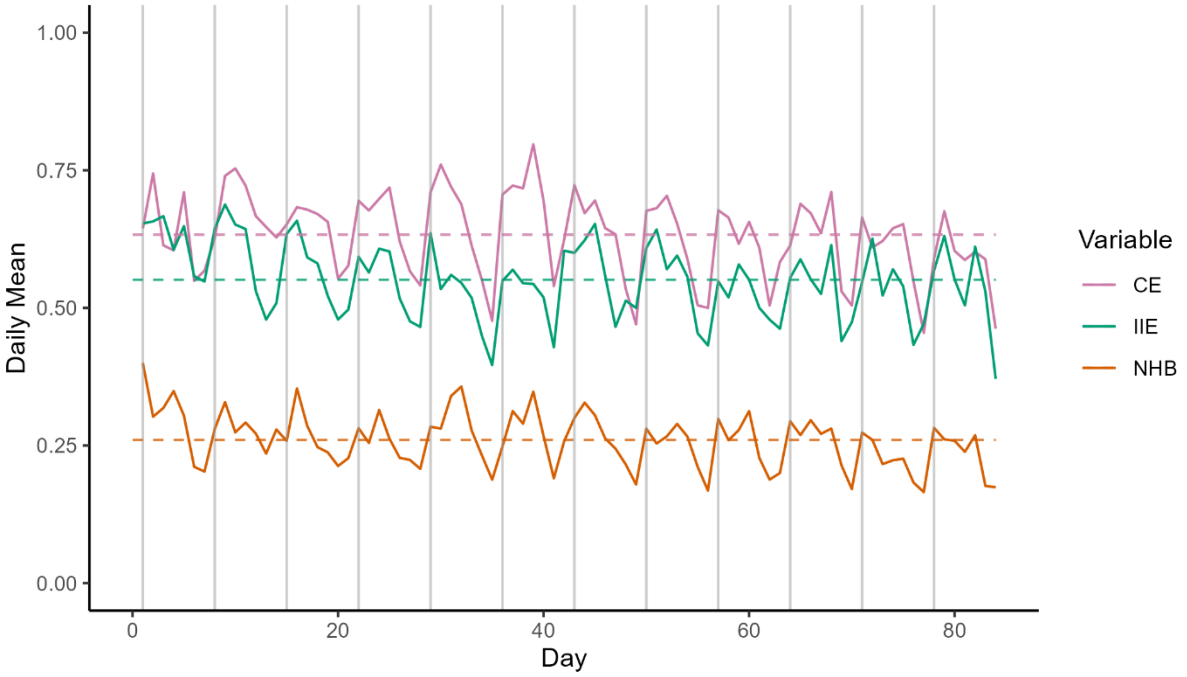
The following plots depict change over time for time varying variables at the sample level (Figures S2.1 & S2.2), and examples of individual time series depicting within person change for intention, stress, reward, cue encounter, non-performance of habitual behaviour and implementation intention enactment (Figures S2.3-.8). Individual time series have been selected based on variance to display a range of different types of trajectories. The plots have been adapted from a recent tutorial (Siepe et al., 2025). For more information and data visualizations about the habit strength (Self-Report Behavioural Automaticity Index) trajectories, see our previous publication (Edgren et al., 2024).

Figure S2.1. Sample level changes in daily mean scores of continuous variables.



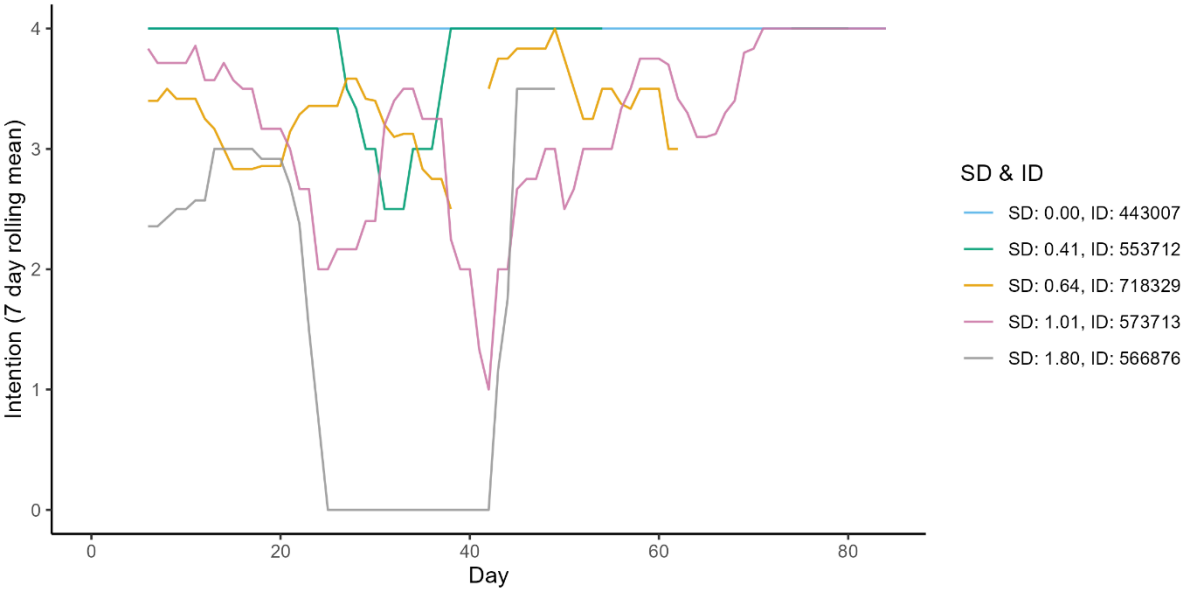
Note. Vertical grey lines represent Mondays; Solid lines indicate mean daily score for the corresponding variable across all participants. Dashed lines indicate the variable mean across all time points and participants; SRBAI: Self-Report Behavioural Automaticity Index.

Figure S2.2. Sample level changes in daily mean scores of dichotomous variables.



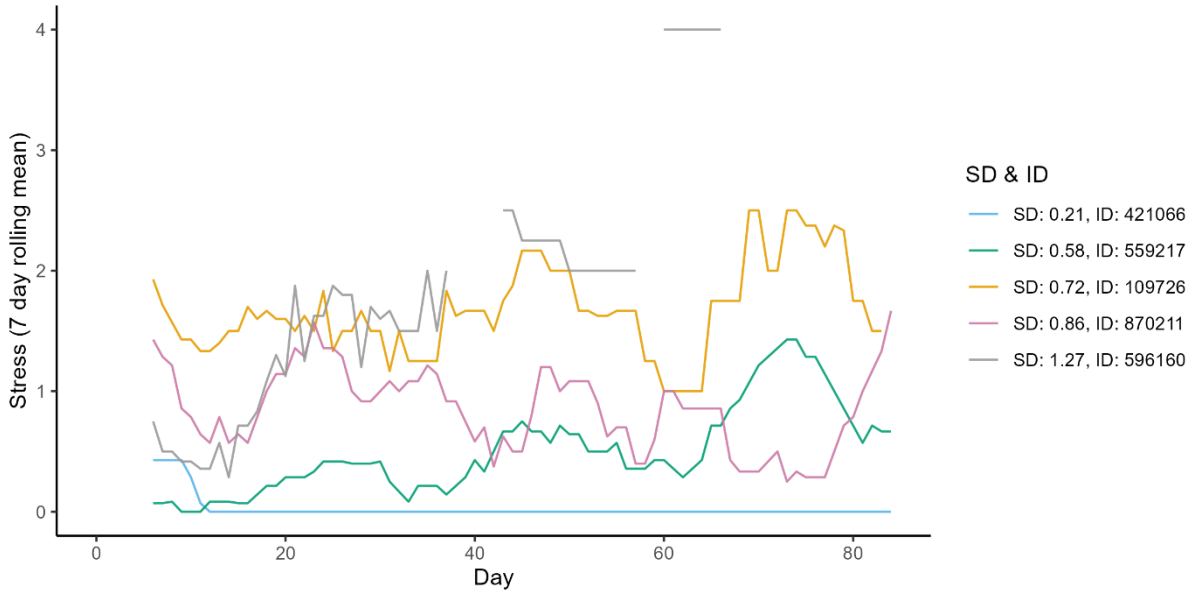
Note. Vertical grey lines represent Mondays; Solid lines indicate mean daily score for the corresponding variable across all participants. Dashed lines indicate the variable mean across all time points and participants; CE: Cue encounter; IIE: Implementation intention enactment; NHB: Non-performance of habitual behaviour.

Figure S2.3. Within person change of intention (n = 5).



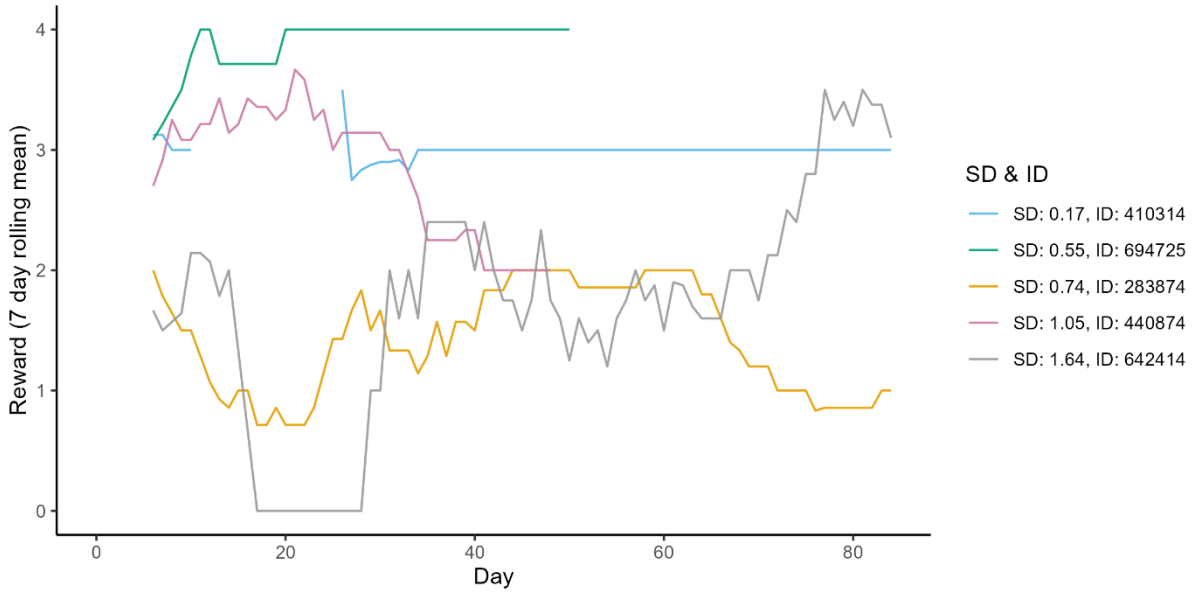
Note. SD: Standard deviation.

Figure S2.4. Within person change of stress (n = 5).



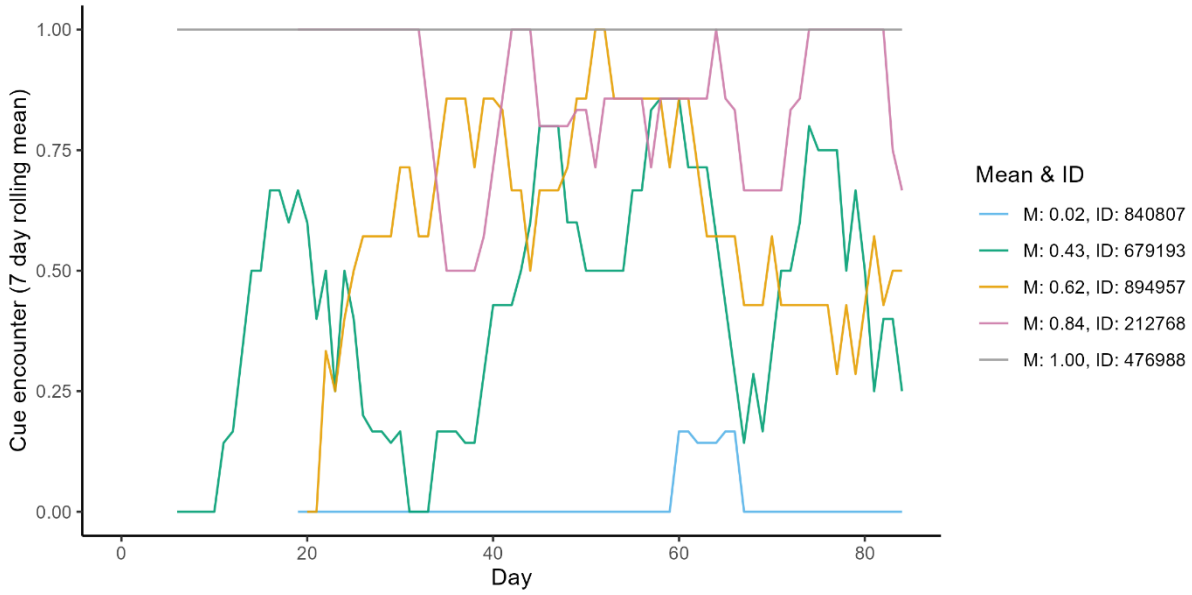
Note. SD: Standard deviation.

Figure S2.5. Within person change of reward (n = 5).



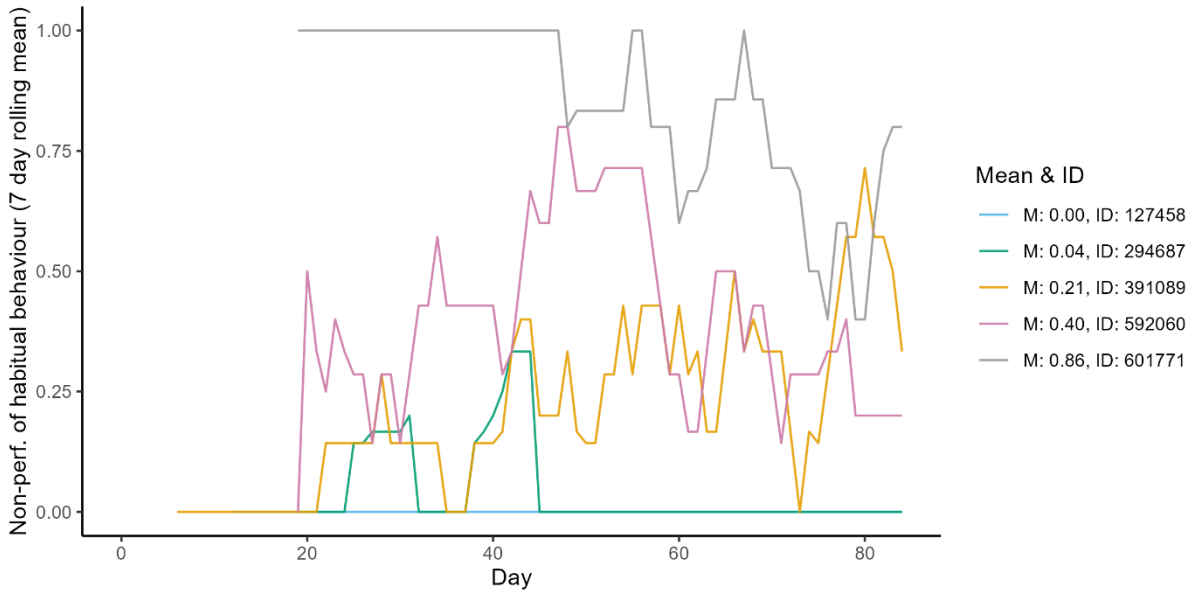
Note. SD: Standard deviation.

Figure S2.6. Within person change of cue encounter (n = 5).



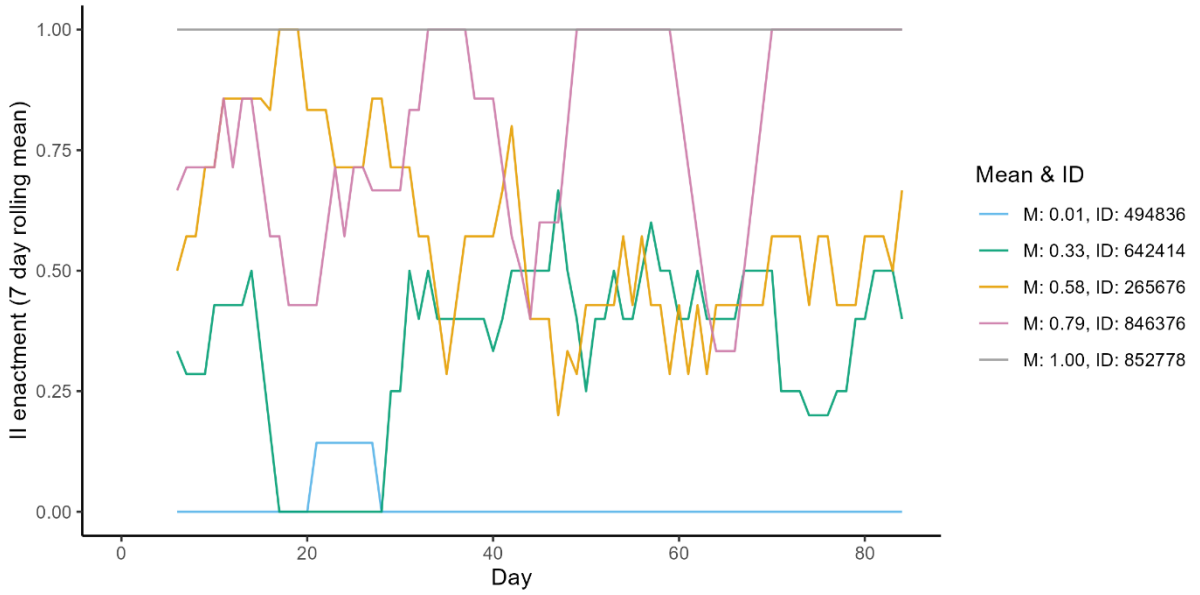
Note. M: mean.

Figure S2.7. Within person change of non-performance of habitual behaviour (n = 5).



Note. Non-perf.: non-performance; M: mean.

Figure S2.8. Within person change of implementation intention enactment (n = 5).



Note. II: Implementation intention; M: mean

7.3.2 Multiple linear regression

For multiple linear regression (Table S2.1) 63 participants were dropped from analysis due to missing habit strength on Day 91, and 5 dropped because the cue category could not be defined, 2 dropped because the habit degradation strategy could not be defined and 2 dropped because an if-component of the II was not provided precluding evaluation of if-component specificity (total n = 72 dropped from analysis). Multiple linear regression models were also run with missing Day 91 observations replaced with the last habit strength observation as the outcome variable (not displayed), which largely replicated results displayed below.

Table S2.1. Multiple linear regression model predicting habit strength at Day 91 by person and cue related factors, degradation strategy, implementation intention characteristics and initial habit strength (n = 122).

Parameters	Estimate	*SE*	*95% CI*	*p**
Intercept	2.85	2.01	-1.15, 6.84	1.00
Day 7 habit strength	0.47	0.14	0.19, 0.74	0.040
Context stability: mood	-0.22	0.16	-0.54, 0.10	1.00
Context stability: time	-0.01	0.13	-0.26, 0.24	1.00
Context stability: place	0.15	0.15	-0.14, 0.44	1.00
Context stability: people	0.11	0.09	-0.07, 0.29	1.00
Cue: physical context	-0.03	0.32	-0.65, 0.60	1.00
Cue: social context	-0.60	0.40	-1.39, 0.19	1.00
Cue: emotion/cognition	0.26	0.36	-0.45, 0.97	1.00
Cue: action/temporal context	0.04	0.27	-0.50, 0.59	1.00
Autonomous motivation	-0.07	0.14	-0.34, 0.20	1.00
Controlled motivation	0.03	0.11	-0.18, 0.25	1.00
Self regulation	-0.62	0.28	-1.18, -0.06	0.910
Strategy: Inhibition	0.24	0.57	-0.89, 1.38	1.00
Strategy: Discontinuation	0.23	0.79	-1.35, 1.81	1.00
Non-valid implementation intention	0.12	0.94	-1.75, 2.00	1.00
If -word used	0.37	1.24	-2.09, 2.83	1.00
Then -word used	0.26	0.22	-0.18, 0.71	1.00
Negation	-0.10	0.66	-1.41, 1.20	1.00
Multiple II formulated	0.92	1.84	-2.73, 4.57	1.00
If-component specificity	-0.32	0.24	-0.80, 0.17	1.00
Then-component specificity	0.06	0.23	-0.41, 0.52	1.00
Intended outcome: avoid target behaviour	-0.25	0.34	-0.93, 0.43	1.00
Intended outcome: reduce target behaviour	-0.26	0.44	-1.13, 0.61	1.00
II updated on day 48	0.18	0.23	-0.27, 0.64	1.00
Response type:				
New behaviour	-0.13	0.86	-1.84, 1.58	1.00
Replace behaviour	-0.08	0.69	-1.46, 1.30	1.00
Set limits	0.24	0.49	-0.72, 1.21	1.00
Direct attention	-0.24	0.62	-1.48, 1.01	1.00
Affect regulation	0.80	0.70	-0.59, 2.19	1.00
Boost self-efficacy	0.58	0.93	-1.26, 2.42	1.00
Sum of response types	-1.08	0.58	-2.23, 0.07	1.00

Note. CI: Confidence interval; II: Implementation intention; Confidence intervals and p-values calculated with Wald t-distribution approximation; *p-value adjusted with the sequentially rejective Bonferroni method.

7.3.3 Multilevel models

The below Table S2.2 displays the fit indices for all multilevel models conducted. On the following page, Table S2.3 displays the multilevel model conducted as part of sensitivity analyses of this study. This model (Model 2s) is an extension of Model 2 displayed in the manuscript, which additionally includes behaviour group effects. In Table S2.3 we see that Model 2s fixed and random effect parameters are very similar to the corresponding Model 2 displayed in the article manuscript. One exception to this similarity is the fixed effect estimate for between person effect of implementation intention enactment, which is negative in the sensitivity analysis below (B = -0.05) but positive in the manuscript Model 2 (B = 0.02). This discrepancy is likely due to the large uncertainty associated to this statistically non-significant parameter.

Table S2.2. Fit indices for multilevel models predicting daily habit strength.

Model	*AIC*	*BIC*	*R2* (cond.)	*R2* (marg.)	*ICC*	*RMSE*
Model 1	7088.1	7403.3	0.905	0.403	0.841	0.316
Model 2	6106.4	6441.9	0.895	0.432	0.815	0.320
Model 2s	6111.3	6467.4	0.896	0.437	0.815	0.320

Note. Model 1 n = 188 and observations = 8136; Model 2 and 2s n = 160 and observations = 6962. AIC: Akaike information criterion; BIC: Bayesian information criterion; R2: R-squared; cond: conditional; marg: marginal; ICC: Intraclass correlation coefficient; RMSE: Root mean square error.

Table S2.3. Multilevel model conducted as sensitivity analyses predicting daily habit strength by person, cue, behaviour and planning related factors while controlling for behavioural group effects (n = 160).

Parameters	Estimate (*SE*)	*95% CI*	Adjusted p*	β**	Random effects: *SD*
Intercept	1.53 (0.30)	0.93, 2.13	**<.001**	0.01	0.69
Time	0.19 (0.11)	-0.05, 0.42	1.00	0.04	0.64
Time^2	-0.32 (0.18)	-0.68, 0.05	1.00	0.04	1.29
Time^3	0.21 (0.08)	0.05, 0.37	0.185	0.02	0.62
Lag-1 habit strength (centred at initial score)	0.32 (0.02)	0.28, 0.36	**<.001**	0.31	0.19
Initial habit strength (grand mean centred)	0.69 (0.07)	0.56, 0.83	**<.001**	0.52	
Perceived stress (between)	0.21 (0.09)	0.03, 0.38	0.358	0.11	
Perceived stress (within)	0.01 (0.01)	-0.00, 0.02	1.00	0.01	
Intention (between)	-0.10 (0.11)	-0.32, 0.11	1.00	-0.07	
Lagged intention (within)	-0.02 (0.01)	-0.04, 0.01	1.00	-0.01	0.08
Cue encounter (between)	0.17 (0.24)	-0.31, 0.64	1.00	0.04	
Cue encounter (within)	0.10 (0.01)	0.07, 0.13	**<.001**	0.04	
Non-perf. of habitual behaviour (between)	-0.35 (0.28)	-0.90, 0.20	1.00	-0.07	
Non-perf. of habitual behaviour (within)	-0.10 (0.01)	-0.13, -0.07	**<.001**	-0.03	
Perceived reward (between)	0.17 (0.11)	-0.04, 0.39	1.00	0.12	
Perceived reward (within)	-0.06 (0.01)	-0.07, -0.04	**<.001**	-0.04	
Strategy: Inhibition	-0.09 (0.13)	-0.34, 0.16	1.00	-0.04	
Strategy: Discontinuation	-0.27 (0.25)	-0.77, 0.23	1.00	-0.04	
II enactment (between)	-0.05 (0.23)	-0.51, 0.41	1.00	-0.01	
II enactment (within)	-0.05 (0.02)	-0.09, -0.01	0.425	-0.02	0.20
Unhealthy snacking group	0.00 (0.16)	-0.32, 0.32	1.00	0.00	
Alcohol consumption group	-0.11 (0.17)	-0.43, 0.22	1.00	-0.04	
Tobacco smoking group	0.05 (0.17)	-0.28, 0.38	1.00	0.02	
Residual					0.33

Note. Time (days) is scaled and centred at the end of the study (i.e. day 91); Degradation strategies are dummy coded, with substitution as the reference category; Behaviour group predictors are dummy coded with sedentary behaviour as the reference category; Between effect predictors are person mean variables; Within effect predictors are person mean centred variables; *p-value adjusted with Holm's (1979) method; **β are standardized coefficients based on a complete model re-fit with a standardized version of the data. CI: Confidence interval (calculated with Satterthwaite approximation); II: Implementation intention; Non-perf: Non-performance.

8. Supplementary material III

This is the supplementary material that accompanies the article preprint (Manuscript III):
Edgren, R., Baretta, D., & Inauen, J. (2025). Degrading unhealthy snacking habits in the real world: A randomised controlled intensive longitudinal study.
https://doi.org/10.31219/osf.io/z5gd7_v2

8.1 Methods

8.1.1 Sample size justification

A total of 307 participants were aimed to be recruited, with 43 participants per group for the six intervention groups and 49 participants for the control group. The rationale for the sample size was based on an ANCOVA power analysis, which aimed to detect a main effect for intervention group (three strategies) and reward in predicting average habit strength at the study's conclusion. The smallest effect size of interest was defined as a 0.5 difference in habit strength (on an SRBAI scale ranging from 0-4) between groups. Specifically, an a priori ANCOVA (3x2 factorial design) was conducted with a Bonferroni-corrected alpha value of 0.05/6 and a beta value of 0.8. Based on data from our previous study(Edgren et al., 2024), the standard deviation was presumed to be 1, and the R-squared value of initial habit strength (as a covariate) was presumed to be 0.12. Consequently, the smallest effect size of interest was considered small-to-medium (Cohen's $d = 0.50$). Power analyses were conducted using exact estimation with the R package Superpower (Lakens & Caldwell, 2021). This analysis concluded that 180 participants were required (30 participants per group across six groups). It was further verified that for comparisons involving the control group with all experimental groups combined, the control group required an additional four participants (N=34) to achieve 80% power to detect a group difference of 0.5 in habit strength (with an alpha of 0.05, standard deviation of 1, and R-squared of 0.12). Therefore, the total required sample size was 214 participants. Using an expected retention rate of 70% and rounding upwards to ensure equally sized groups, a total sample size of 307 was required for recruitment. For hypotheses concerning the rate of change, the previously described power analysis was considered sufficient to detect small-to-medium effect sizes (Cohen's $d = 0.50$). The estimated retention rate was based on a previous study (Edgren et al., 2024), where the retention rate was 60%; however, planned procedural changes, such as shorter questionnaires and providing compliance information during study participation, aimed to improve this retention rate by 10%. Substantial interindividual differences in habit strength trajectories were expected based on our previous study (Edgren et al., 2024). Due to these interindividual differences, power analysis was not conducted for analyses based on asymptotic modelling. Specifically, it was not expected that decreasing habit strength trajectories would be adequately described by an asymptotic trend across the entire sample, which made reliable power analysis difficult for such cases.

8.1.2 Reward pilot study

Methods. An initial list of 107 reward messages were created by the research team. The reward messages were created such that they contained, to varying degrees, congratulating text on accomplishment, and text intending to address the participant's competence and autonomy. For generating these reward messages, ChatGPT (OpenAI, 2025) (version GPT-3.5) was used.

Subsequently, a cross-sectional pilot study was conducted to get initial feedback on how these reward messages are perceived. For evaluating perceived reward, each message was evaluated with adapted items from selected subscales of the Intrinsic Motivation Inventory (IMI) (Ryan, 1982; Ryan et al., 1983). See Table S3.1. for items used. 3 items were selected for each of the Interest/Enjoyment, Perceived competence, and Perceived choice subscales. These three subscales were of primary interest, as they correspond to liking, competence and autonomy. Of note, 1 item from the Perceived Choice subscale was a novel addition: "Reading this message, I feel like I am obliged to change my snacking behaviour" (reverse scored). Additionally, 2 items from the Value/Usefulness subscale (as perceived value could relate to any psychological need). Also, 1 item not related to the IMI was included, namely "This message feels rewarding to me". All items were assessed on a 5-point Likert scale (scored 1-5). Higher scores indicated stronger agreement with the statements, indicating higher perceived reward (except for the previously noted perceived choice item that was reversed scored). As such, in total 12 items were used to evaluate each reward message. Lastly, participants could give open feedback for each reward message.

Table S3.1. Intrinsic Motivation Inventory items used in reward message pilot study.

Subscale	Item wording
Interest/Enjoyment	This message was quite enjoyable.
	This message made me feel good.
	I found this message interesting.
Perceived competence	Reading this message, I feel a little more competent in changing my unhealthy snacking.
	Reading this message, I think I am pretty good at changing my snacking behaviour.
	Reading this message, I feel more satisfied with my performance at changing my snacking behaviour.
Perceived Choice	Reading this message, I feel reassured that changing my snacking behaviour is my own choice.
	Reading this message, I feel more strongly that I want to change my snacking behaviour.
	Reading this message, I feel like I am obliged to change my snacking behaviour.
Value/Usefulness	This message has some value to me.
	I would find it useful to receive this message again in the future.

Note. Item wording is translated from German

Pilot study participants were instructed to imagine themselves taking part in a study where they intend to reduce unhealthy snacking, and that they receive the positive feedback messages in response to successfully avoiding eating unhealthy snacks. Each participant evaluated 23 reward messages. Respondents could enter a raffle to win 1 of 3 supermarket gift vouchers worth 50 CHF for taking part in the study. Data collection took place from January 6th to February 12th, 2024.

Reward messages with the highest mean score (≥3.5) across all items were qualitatively evaluated to identify commonalities and differences among these messages. Similarly, messages with low overall mean scores (<3.0) were evaluated to identify commonalities of content that was not appreciated. Additionally, the open responses participants provided were inspected to identify content that was appreciated or that needed revision. The mean score of reward messages for subscales Interest/Enjoyment, Perceived Choice and Perceived Competence were inspected to see how the messages address these different facets of reward. Subsequently, a new set of 85 (1 unique message per study day from day 7 to 91) reward messages were generated. Here, initial reward messages that had high overall means were used as a reference to generate novel messages with similar content and structure. To ensure variability in the exact wording of reward messages ChatGPT was used to generate novel messages.

Results. In total, 272 participants fulfilled inclusion criteria and provided informed consent. Out of these 68 participants completed the entire survey (i.e. assessed 23 reward messages with 12 items each). An additional 83 participants provided incomplete responses to the survey (i.e. assessing at least some reward messages). Effectively, each reward message was evaluated with 146 to 336 responses (where 1 message was evaluated with a maximum of 12 items by 1 participant). The mean age of the sample that completed the survey (N = 68) was 42.9 years (SD = 15.4), and 55 participants (80%) identified with female gender, and 10 with male gender.

Quantitative findings. In total, 29 reward messages had a mean score of 3.5 or higher across all items (i.e. 0.5 points above scale midpoint). These messages tended to be 1 or 2 sentences in length, often containing over 7 words. These included messages that provided specific feedback to the performed behaviour, praising the participant for their achievement (e.g. “you have proven your assertiveness once again”), acknowledgment of progress made and milestones reached (e.g. “your progress over the last few weeks is really impressive” & “Day 10!”), and emphasizing perseverance (e.g. “You have clearly demonstrated your impressive resilience today!”) and self-determination (e.g. “You are incredibly determined to keep your resolution”). Also, these messages encouraged maintaining progress (e.g. “keep it up!”). Interestingly, messages evaluated as more rewarding did not include emojis. 11 reward messages were scored below the scale midpoint (score below 3). These included short messages (1-2 words), and messages that did not explicitly address the performed behaviour (e.g. “Simply fantastic!”). It seemed that messages that didn’t empower individuals or highlight their agency in decision-making tended to be perceived as less rewarding. All items were scored similarly across each IMI subscales interest/enjoyment, perceived competence, and perceived choice, and these subscale scores corresponded closely to the overall mean score.

Qualitative findings. Participants provided in total 313 open comments in reference to 101 messages. Among these, each reward message received 1-9 open comments. Suggestions for improvement include adding statements such as “well done”, avoiding long and complicated sentences and usage of technical language, and encouragement to reflect on the reasons for behavioural change.

8.1.3 Procedure

Randomisation. The study app, "Habirupt" was developed by the research team in collaboration with the University of Bern Technology Platform for Research using the in-house "self-help" platform which supports app development. Participants were randomly allocated to one of 7 study groups using a restricted randomisation approach to ensure balanced group sizes. The allocation sequence was generated and implemented automatically within the self-help platform using a computerized random number generator. In each allocation cycle, all 7 groups were initially available. The first participant in a cycle was assigned to a randomly chosen group, the second participant randomly assigned to one of the remaining 6 groups, and so forth until all 7 groups had received one participant. The process then repeated for subsequent cycles, ensuring that the distribution of participants across groups remained as even as possible throughout the study. Note that the group counter was initially set to six for all intervention groups and zero for the control group, to ensure that the control group would have 6 participants more than the intervention groups, as per the planned sample size. Consequently, the first 6 participants were assigned to control, after which allocation took place per the above restricted randomisation approach described above with a 1:1 ratio.

Reimbursement. Participants were informed they would receive CHF 120 for full study participation, with a minimum requirement of completing 4/7 end-of-day questionnaires each week. For incomplete participation, participants received CHF 9 per week when they had completed at least four end-of-day questionnaires.

Fixed interval-contingent data collection. The end-of-day questionnaires were estimated to take 2-3 minutes to complete. The end-of-day questionnaire was available in the app from 19:00 PM until 10:00 AM the following morning. The end-of-day questionnaire for Days 1-7 consisted of 15-16 multiple-choice items and two open-ended items. For Days 8-91, the end-of-day questionnaire comprised 22-23 multiple-choice items and one open-ended item.

8.1.4 Experimental manipulation: Group specific manipulation

Instructions during cue identification phase (all participants; days 1-6)
Sometimes we eat unhealthy snacks in response to signs we experience in our daily lives. We would now like to ask you to think about the personal triggers that you experience in your daily life at home and which cause you to consume unhealthy snacks. To do this, please pay attention to your unhealthy snacking behaviour when you are at home during the first 7 days of the study. Both today and in the coming days, we will ask you in the evening what triggers you experienced at home on each day. By **triggers**, we mean things that cause you to consume unhealthy snacks due to a habitual behaviour. For example, seeing the TV or entering the kitchen. There are many other possible triggers. By **habitual behaviour** we mean a behaviour that has become automated due to constant repetition when a trigger occurs. Triggers can be objects, people, routines or times, for example. A strong habitual behaviour is then performed automatically when the trigger occurs. In order to break a habitual behaviour, it is therefore important to first find the trigger. **Here are a few examples:**

- Anna eats a pastry during her afternoon coffee break. Personal trigger: Afternoon coffee break (routine).
- Anna sees the cookie tin in her kitchen cupboard and grabs a cookie straight away. Personal trigger: cookie tin (object).
- At 4 p.m. Anna sits down and eats a cookie. Personal trigger: 4 p.m. (time).

At the end of the first week, you will be instructed to choose a specific trigger that you frequently encounter in your everyday life at home. The goal will be to stop your unhealthy snacking behaviour for this cue for the duration of the study. This is the habit you will try to change.

Here are some more examples of triggers that participants have already mentioned:
- Seeing snacks in the kitchen
- Opening the fridge
- Being home alone
- being at home with someone who is eating snacks
- hunger; thirst
- stress
- Craving for something sweet
- Coffee break in the afternoon
- after lunch

***
Now we would like to ask you what triggers you experience in your everyday life at home that tempt you to consume unhealthy snacks. Writing down the triggers for your unhealthy snack consumption will help you to understand your habitual snacking behaviour.

Please write down the triggers you have experienced at home today.
Example: "Entering the kitchen, sitting on the sofa, ..."

[Open response]

Instructions for cue selection (all participants; day 7)

Welcome to the second part of today's survey!

Now it's time to choose a snacking habit that you would like to change during the study. Before doing so, we would like to explain to you once again what a habit is and how you can change habitual snacking behaviour. This understanding is important for participation in the study.

As a reminder:
By habitual behaviour, we mean behaviour that has become automatic due to constant repetition when a cue occurs. Cues can be objects, people, routines or times, for example. A strong habitual behaviour is performed automatically when the cue occurs. In order to break a habitual behaviour, it is therefore important to first identify the cue.

Here are a few examples:

Anna eats a pastry during her afternoon coffee break.
Personal cue: Afternoon coffee break (routine)

Anna sees the biscuit tin in her kitchen cupboard and grabs a biscuit straight away.
Personal cue: biscuit tin (object)

At 10 a.m. Anna sits down and eats a biscuit.
Personal cue: 10 a.m. (time)

When Anna's friend Josephine arrives, they eat chocolate together.
Personal cue: friend (person)

Now it's your turn to define the cue for your snacking habit that you want to change. Remember, you should focus on this cue of your snacking habit during the 12-week study period.

Below we have compiled the cues that you have observed and reported in your diary over the past week.

You can now choose a cue that best fits the following criteria.

You are also welcome to choose a cue that is not listed here if something comes to mind that fits even better.

This will be the snacking habit that you try to change during the study.

The cues you observed last week:
{piped text of week 1 observed cues}

Choose a cue...
...that you encounter at home
...that you experience about once a day
...that usually tempts you to eat unhealthy snacks

I choose the following cue:
[open response]

Control group instructions (day 7)

You were randomly selected to take part in the control condition of the study.

From a research perspective, this is a very important role. Only with a control group will we be able to determine whether the investigated strategies are indeed effective to disrupt a habit.

We therefore ask you to answer the evening questionnaires over the next 12 weeks and not actively try to change your unhealthy snacking habit.

At the end of the study, you will be given access to all the materials that can help you to break your snacking habits in the future if you wish.

If you have any questions or comments, please feel free to contact us at habirupt.psy@unibe.ch.

Instructions for implementation intention formulation (**all intervention** groups; day 7)

Now it's time to decide how you're going to prevent your unhealthy snack consumption when your "{cue}" cue occurs.

The key to changing a habit lies in the following steps:

- First, you need to identify the cue that is causing the habitual behaviour. You have just completed this step!
- Second, you need to create a plan for how to overcome your habitual behaviour.
- Third, you need to define the preparatory measures you need to implement the plan.
- And fourth, you should consistently implement the plan when you encounter the cue.

In the following, we will support you step by step in changing your habits.

Instructions for implementation intention formulation (**Substitution** group; day 7)

Now we come to the second step for habit change: you create a plan for how to overcome your habitual behaviour.

Habit research suggests that replacing an old habitual behaviour with a new behaviour can help to successfully break the old habit.

Example: Anna wants to change her habit of eating a pastry with her coffee in the afternoon. She therefore plans to eat a fruit instead of a pastry (substitute behaviour).

Now it is up to you to decide which alternative you want to use to replace the unhealthy snack when your cue "{cue}" occurs. There are two different options:

[1] replace the unhealthy snack with a healthy one (e.g. fruit or nuts)
[2] Replace the unhealthy snack with something completely different (e.g. go for a walk)

***
If [1] was selected:

For your cue "{cue}", you have chosen to consume something else in place of the unhealthy snack.

Examples:
- eat fruit or nuts instead of an unhealthy snack
- drink unsweetened coffee, tea or water instead of an unhealthy snack

Now we would like you to formulate an if-then plan.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert your cue], **then I will** [insert your healthy snack].

Example: "If I drink a coffee in the afternoon, then I will eat an apple."

In this example, "drink coffee in the afternoon" is the cue and "eat an apple" is the replacement action.

***
If [2] was selected:

For your cue "{cue}", you have chosen to replace the unhealthy snack with something completely different.

Examples:
- go for a walk
- Doing sport
- reading
- brush your teeth

Now we would like you to formulate an if-then plan.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert your cue], **then I will** [insert your alternative activity].

Example: "If I drink a coffee in the afternoon, then I will read a book."

In this example, "drink coffee in the afternoon" is the cue and "read a book" is the alternative activity.

***
[1]&[2]:

Please now write down your if-then plan exactly according to this scheme.

Please note that you will keep to this plan for the next 12 weeks and cannot change it.
[open response]
***

If [1] was selected:

Now we come to the preparatory step for habit change:

Please think about the preparatory measures needed to implement your plan.

This could be, for example:
- buy the selected substitute product
- keep the replacement product in the right place (e.g. next to the sofa or in the kitchen)
- set a notification / reminder on your mobile device
- put a handwritten note where you can see it
- discuss your plans with people close to you
***

If [2] was selected:

Now we come to the preparatory step for habit change:

Please think about the preparatory measures needed to implement your plan.

This could be, for example
- setting a notification / reminder on your mobile device

- Put a handwritten note where you can see it
- Discuss your plans with people close to you

***

[1]&[2]:

What do you need to do to realise your plan? [open response]

Instructions for implementation intention formulation (**inhibition** group; day 7)

Now we come to the second step for habit change: you create a plan for how to overcome your habitual behaviour**.**

Habit research suggests that it can be helpful to inhibit the habitual behaviour when the cue occurs.

Example:
Anna wants to change her habit of eating a pastry with her coffee in the afternoon. She could plan to avoid eating the pastry by thinking about her goal of not eating pastries.

Now it's up to you to decide how you want to inhibit your unhealthy snack consumption when your cue "{cue}" occurs. There are several ways to do this:

[1] think of something motivating (e.g. your goals)
[2] think of the limits you set for yourself (e.g. that you do not eat any chocolate during the week)
[3] Redirect your attention (e.g. think about something else)

***
If [1] was selected:

Think about how you want to motivate yourself.

Examples:
- Think about your goal of not snacking
- telling yourself that you can resist the craving for snacks by simply waiting
- telling yourself that snacking will not improve the situation

Now we would like you to formulate an if-then plan.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert your cue], **then I will** [insert your motivating thought].

Example: "If I'm in the kitchen at home, then I will tell myself that I can resist the craving for snacks by simply waiting."

In this example, " in the kitchen at home" is the cue and "then I will tell myself that I can resist the craving for snacks by simply waiting" is the motivating thought.

***
If [2] was chosen:

Think about how you want to set limits for yourself.

Examples:
- not allowing yourself to look in the fridge
- only eat snacks on special occasions (e.g. on holidays)
- only eat snacks on certain days

Now we would like you to formulate an if-then plan.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert your cue], **then I will** [insert your limit].

Example: "If I'm in the kitchen late in the evening, I won't allow myself to open the fridge."

In this example, " in the kitchen late in the evening" is the cue and "then I will not allow myself to open the fridge" is the limit.

***
If [3] was chosen:

Think about how you can focus your attention elsewhere when your cue "{cue}" occurs.

Example:
- pause for a moment and focus on my breathing
- think about what was the funniest thing that happened today
- count backwards from 20

Now we would like you to formulate an if-then plan.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert your cue], **then I will** [insert your inhibiting action].

Example: "When I'm in the kitchen late in the evening, I will stop and focus on my breathing."

In this example, " in the kitchen late in the evening" is the cue and "then I will stop and focus on my breathing" is the inhibitory action.

***
[1]&[2]&[3]:

Please now write down your if-then plan exactly according to this scheme.

Please note that you can keep to this plan for the next 12 weeks and cannot change it.
[open response]

***
[1]&[2]&[3]:

Now we come to the third step for habit change:

Please think about the preparatory measures needed to implement your plan.

This could be, for example
- setting a notification / reminder on your mobile device
- Put a handwritten note where you can see it
- Discuss your plans with people close to you

What do you need to do to realise your plan? [open response]

Instructions for implementation intention formulation (**Reduced accessibility** group: day 7)

Now we come to the second step for habit change: you create a plan for how to overcome your habitual behaviour**.**

Habit research suggests that limiting the availability of a behaviour can help to break the habit. So, making sure to not have snacks available at home.

Example:
Anna wants to change her habit of eating a pastry with her coffee in the afternoon. She could plan to give away her existing pastries when she gets home tonight, and therefore will no longer have pastry at home.

Now we would like you to formulate an if-then plan to no longer have snacks available at home.

Scientific studies show that creating a precise if-then plan helps you to implement it in the future.

Importantly, an if-then plan should have the following format:

If I [insert when you will limit the availability of snacks], **then** [insert how you will limit the availability].

Example: "If I arrive home in the evening, then I will give all unhealthy snacks to my neighbour."

In this example, " arrive home in the evening " is the cue and "give all unhealthy snacks to my neighbour " is restricting the availability of the unhealthy snacks.

Other ways to limit the availability could be to:

- Put the snacks out of your home in a very inaccessible place
- Have another person from your household lock the snacks in a cupboard to which you do not have access
- When you have used up the snacks, do not buy any more

Please now write down your if-then plan exactly according to this scheme.
Please note that you can keep to this plan for the next 12 weeks and cannot change it.
[open response]

***

Now we come to the third step for the habit change:

Please think about any other preparatory measures needed to implement your plan.

This could be, for example

- set a notification/reminder on your mobile device or write a handwritten note to stop buying new snacks
- Discuss your plans with people close to you (e.g. persons you live with)
- Avoid the supermarket sections with unhealthy snacks
- Don't go shopping when you're hungry

Now please indicate what other actions you would like to take to ensure that you do not encounter unhealthy snacks when your "{cue}" cue occurs.
[open response]

Instructions for intervention phase (**all intervention** groups; day 7)

Congratulations!

You now have an if-then plan to help you stop your unhealthy snack consumption when your cue occurs. You can view this at any time from now in the "My Plan" tab. In this tab you can also see the preparatory steps you set yourself.

We now come to the last step for the habit change:

From now on, you will be prompted to stop your unhealthy snack consumption using your If-Then Plan when your cue occurs. Please try to consistently implement your plan each time you encounter your chosen cue. It is important for the study that you apply the formulated plan and do not try out any other strategies during the study.

Over the next 12 weeks, we ask you to record every encounter with your cue in the app.

It is important that you record these encounters as soon as possible after they occur. This only takes a few seconds. You can now record events at any time in the trigger questionnaire on the start page of the app. Please note that you can complete the trigger questionnaire repeatedly (whenever you encounter the trigger). In addition, unlike the evening questionnaire, the trigger questionnaire is available throughout the day.

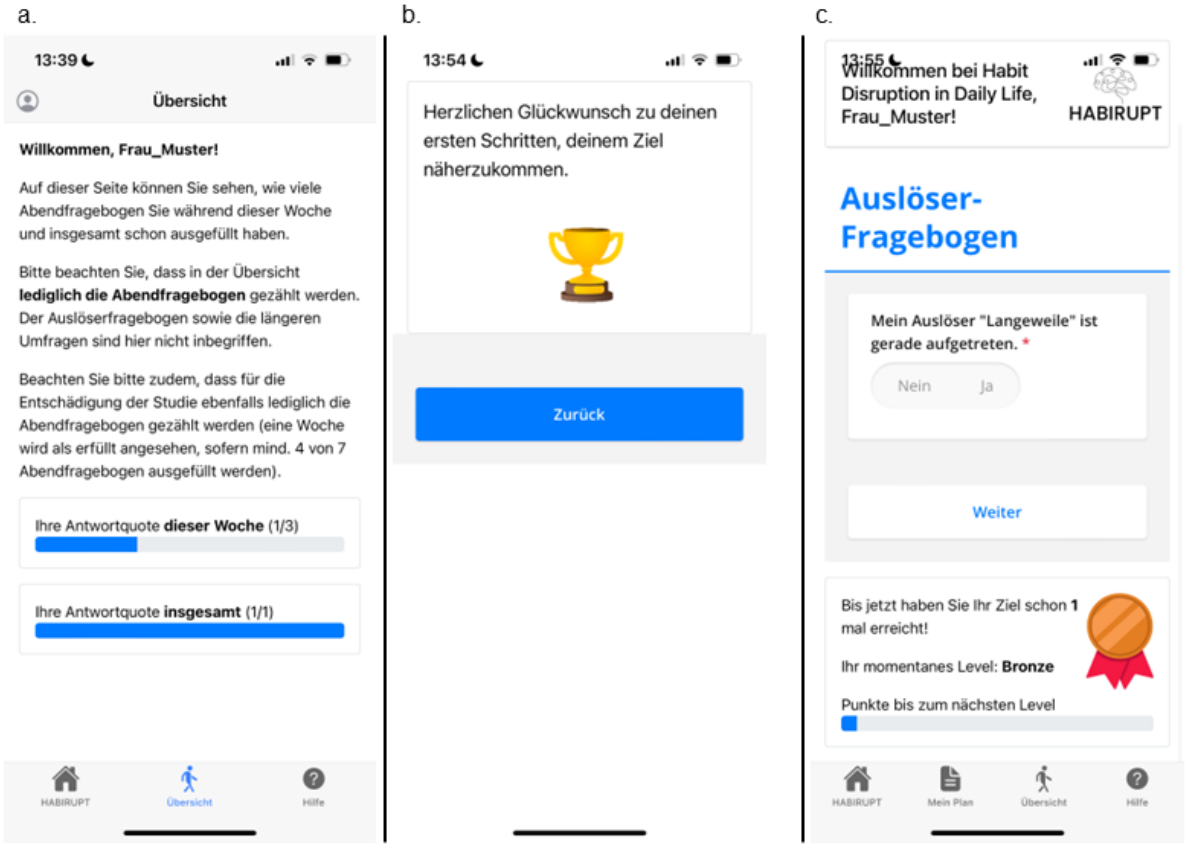
We ask you to test this function immediately after completing this survey.

We also ask you to complete the evening diary questionnaires as before.

If you have any questions or comments, please feel free to contact us at habirupt.psy@unibe.ch.

8.1.5 Experimental manipulation: App features

Figure S3.1. Screenshots from smartphone app.



Note. Screenshots have been taken by the research team. **a. App overview tab** displays the number of end-of-day questionnaire responses completed for the current week and for the entire study duration with a progress bar. The progress bar was unrelated to reward and could be viewed by all participants. Note that the progress bar values are faulty in the displayed example. **b. Reward message pop-up screen** displaying a reward message and an animated trophy graphic. **c. App homepage tab** during the intervention phase for a participant in the reward condition. The upper half of the tab contains the continuously available event-contingent questionnaire labelled "Auslöser-Fragebogen" (Eng. Cue questionnaire). In the lower half of the tab are displayed the in-app points accumulated for encountering cue without subsequent unhealthy snacking (here 1 point), the accomplishment tier based on accumulated points (here bronze), and a progress bar indicating when the next accomplishment tier (silver, gold or diamond) will be achieved.

Table S3.2. Example reward messages used in the study.

Timing (study day)	Reward message
7	Congratulations on your first steps towards your goal.
8	Today you proved your discipline by successfully resisting the temptation of unhealthy snacks. Well done!
18	Brilliant! What you have achieved is down to your own determination alone!
21	Hats off, you did a great job today! You have now already mastered 2 weeks.
38	Impressive! You successfully put your resolution into practice, you can be proud of yourself!
53	Your willpower is simply impressive! Stay committed!
60	60 days have already passed! You have unequivocally showcased your determination!
91	Congratulations to you! You have reached the end of this study duration and have proven that determination and perseverance pays off. These qualities promise great success for your future. Celebrate this achievement, because you have truly earned it!

*Note***.** Reward messages are translated from German; Full list of original reward messages are available online (https://osf.io/z7tby/).

8.1.6 Methods for intervention fidelity and manipulation check

Intervention fidelity was assessed in relation to strategy and reward. First regarding strategy, in the post-study survey, participants reported of any additional strategies they might have used (subsequently referred to as blended strategy use) to degrade their unhealthy snacking habit beyond the strategy inherent to the experimental manipulation. Also, during data processing, the actual strategies used in the implementation intentions were manually coded as a fidelity check to verify congruence with assigned strategy. These fidelity assessments reflect treatment enactment (Hankonen, 2021).

Regarding intervention fidelity of reward, the duration of time, in seconds, spent with an in-app pop-up screen displaying a reward message was recorded. This served as an intervention fidelity check for treatment receipt (Hankonen, 2021). Regarding the manipulation check of reward, perceived reward was assessed using a single 5-point Likert scale item: "Just now, that I didn't eat any unhealthy snacks in my selected situation felt good" (answer options: not true–completely true) on 12 prespecified occasions (2nd, 5th, 10th, 15th, 21st, 32nd, 45th, 50th, 61st, 78th, 80th, and 88th sequential occasion reward delivery) to participants in a reward condition (see manuscript Figure 10). The event-contingent perceived reward question was available for participants for 30 minutes after they had recorded avoiding unhealthy snacking in response to a cue encounter.

8.1.7 Event contingent data processing

The event-contingent data was cleaned as follows (procedure established post-hoc). First entries with missing data in all key variables were removed (k = 2,110 entries removed), along with entries where the cue was reportedly not encountered (contradicts intended event-contingency, k = 1,857 entries removed). Then duplicate entries (defined as entries < 50 seconds apart based on data familiarization) were removed (k = 116 entries removed) by retaining the temporally

last entry, while ensuring no data loss (imputing missing data if available in temporally earlier duplicate entry).

8.1.8 Main analysis assumption testing

For ANOVA based analyses, the normality of residuals (Shapiro-Wilk test (Royston, 1982)), and homogeneity of variances (Levene's test (Levene, 1960)) were checked. For ANCOVA based analyses, linearity between covariate and dependent variable (visual inspection of scatter plot), and homogeneity of regression slopes (fitting model with interaction term and testing significance of interaction term) were additionally checked. For analyses predicting rate of change H2.1 (weeks 1 and 2) and H2.2-.3 (weeks 1 and 2), the normality of residuals assumption was violated, for which reason robust ANOVA (H2.1) and robust regression (H2.2-.3) were conducted as sensitivity analyses. For analyses predicting time needed to reach the lower 95% asymptote (H2.4-.6) initial non-normality of residuals was handled with log-transformation of the dependent variable. For analysis predicting the binary outcome of reaching 95% asymptote (H1.4-.6) assumptions of logistic regression were evaluated by checking multicollinearity (variance inflation factor), linearity of logit (Box-Tidwell test(Box & Tidwell, 1962)), checking for influential observations, and goodness of fit (Hosmer-Lemeshow test (Hosmer & Lemeshow, 2000)). For H1.5-.6, the Hosmer-Lemeshow test was initially below the threshold for good fit ($p < .05$). Sensitivity analysis excluding flagged influential cases improved the model fit ($p = 0.20$), while all predictors remained non-significant. Given the stability of results and the absence of data errors, all cases were retained in the final analysis.

8.1.9 Statistical software

Within-person asymptotic models were estimated using the 'stats::Ssasymp()' base R function and the 'nls.multstart' R package(Padfield & Granville, 2020) to iteratively test multiple starting values for each within-person time series. GAMs were estimated using the 'mgcv' R package (S. N. Wood, 2003), and the 'gratia' R package (Simpson, 2024) was used to obtain the first derivatives. ANOVA and ANCOVA analyses were run with R package 'afex' (Singmann et al., 2024).

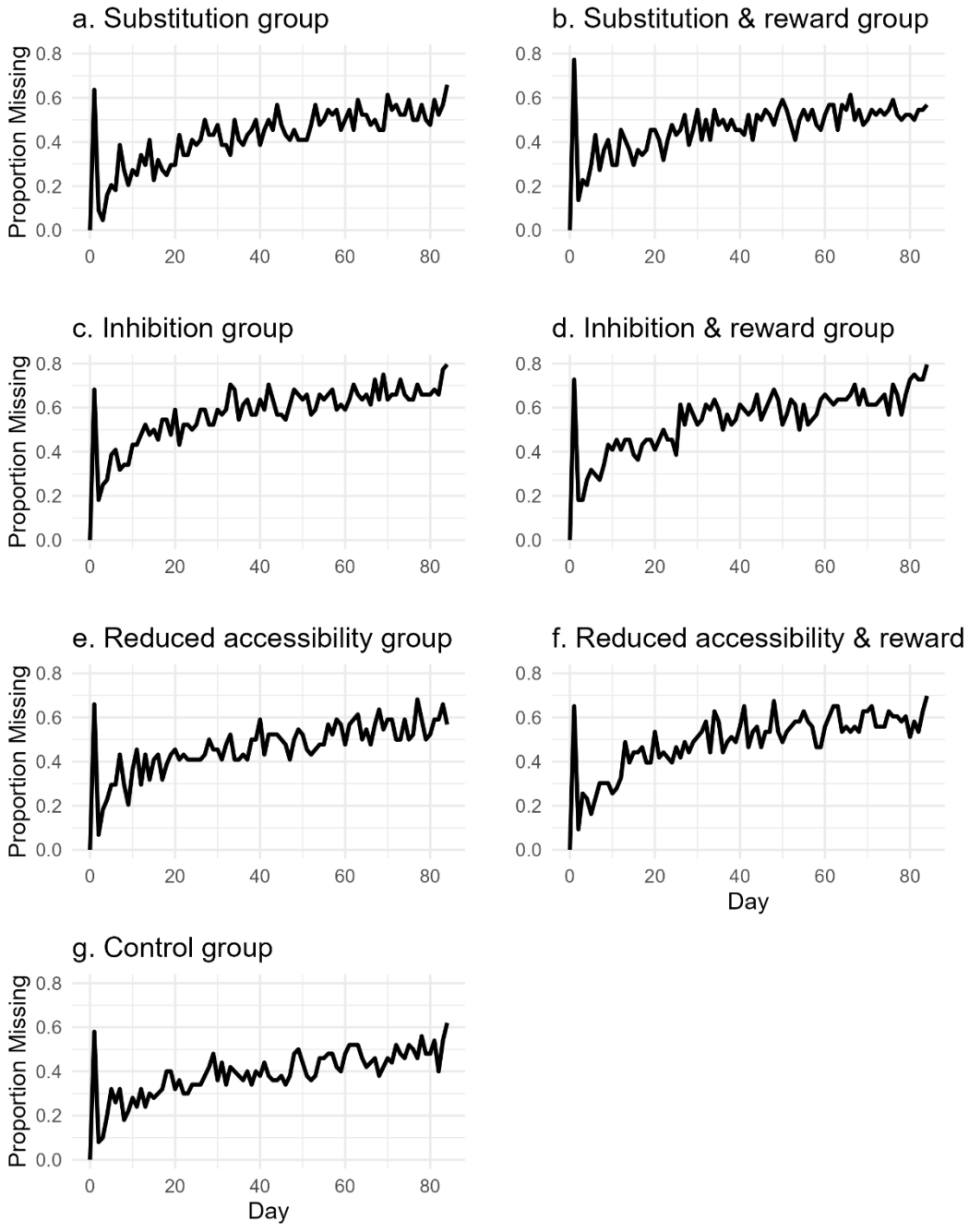
8.1.10 Deviation from protocol

The preregistration stated the perceived reward item would be delivered to all intervention group participants, and not only reward condition participants as conducted. This deviation was made to avoid inducing reward to the non-reward condition participants through enhanced self-monitoring. Further, participants were not excluded from primary analyses based on not affirming plan enactment at least once during the study as stated in the preregistration. This deviation was made because of participants' low uptake of responding to the event-contingent questionnaire, which would have led to a reduction in statistical power if participants were excluded. Sensitivity analysis with reassigned actual strategy group and exclusion of blended strategy use was added post-hoc.

8.2 Results

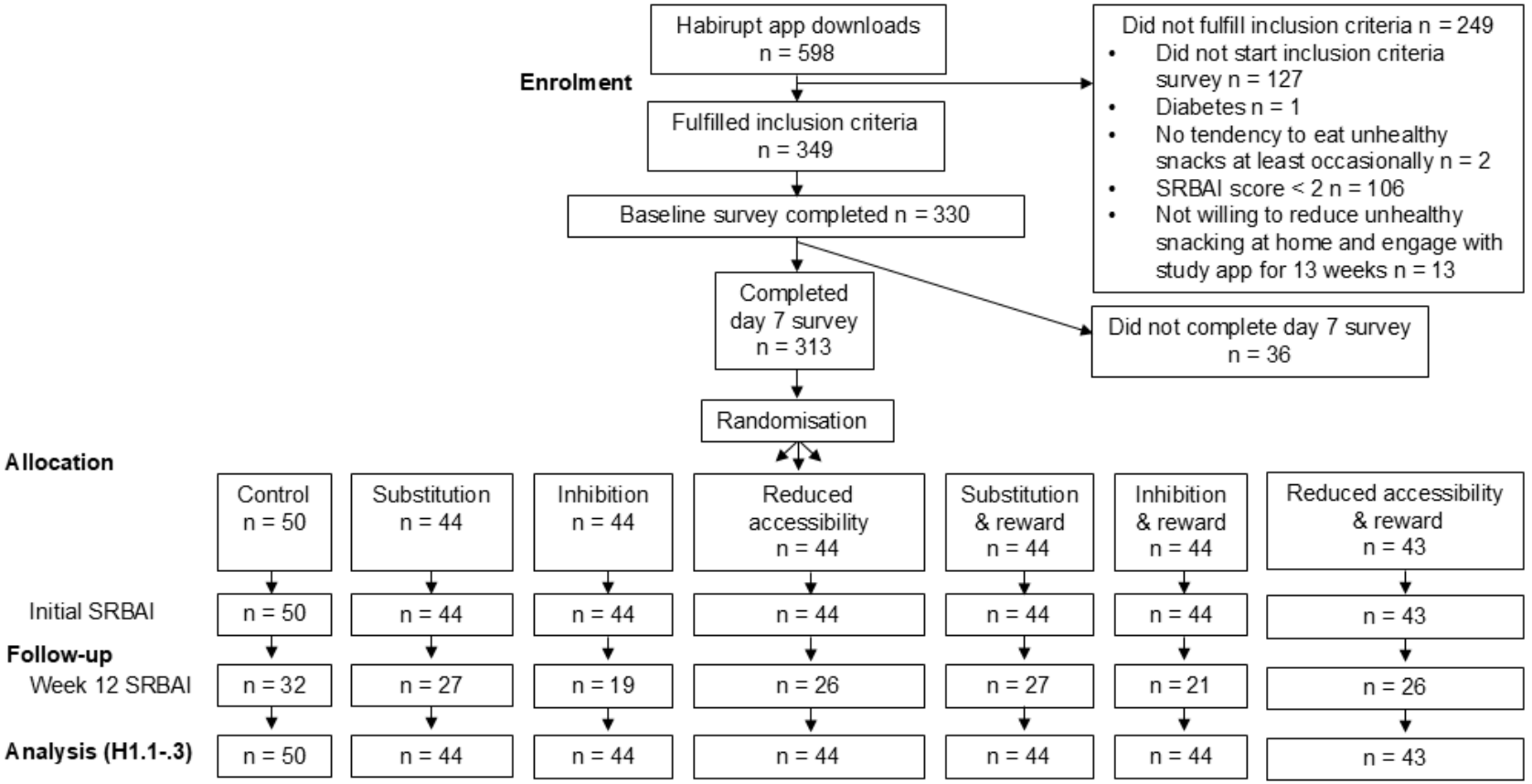
8.2.1 Participant retention and habit strength observations

Figure S3.2. Proportion of missing daily habit strength observations by allocated intervention group.



Note. Day ranges from 0-84, where day 0 corresponds to day 7 (initial habit strength measurement) and subsequent days the entire intervention phase. The spike in proportion of missing habit strength observations on day 1 of the intervention phase, was presumably due to a technical issue with the app. Comprehensive heat maps of habit strength values and missing observations are available in the online repository time series data visualizations file (https://osf.io/z7tby/).

Figure S3.3. Participant flow chart.

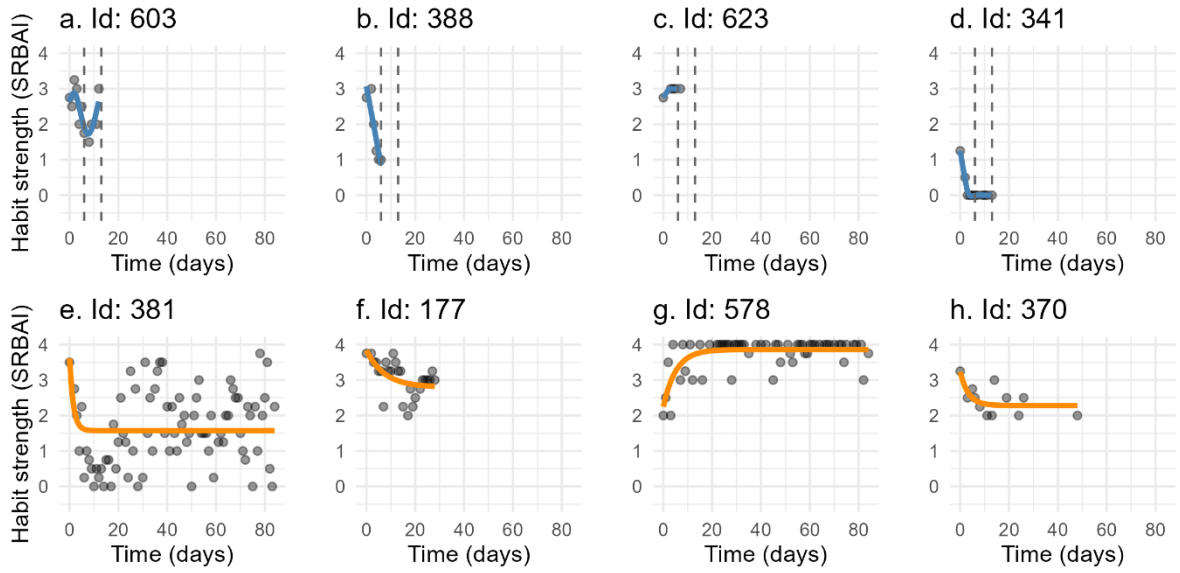


Note. For group specific sample sizes of other primary analyses see Table S3. SRBAI: Self-Report Behavioural Automaticity Index.

8.2.2 Within-person habit degradation trajectories and outcomes extracted

Within-person asymptotic models were sequentially deemed invalid (n = 234) first due to missing gaps of observations longer than 21 days (n = 122), then due to displaying an increasing trend (n = 29), and lastly due to poor absolute fit (RMSE > 0.33; n = 83). Regarding generalized additive models (GAMs), in 10 instances person-specific models could not be estimated because only 1 observation was recoded (initial habit strength on day 7), and in 31 instances the time series did not meet the criteria of having at least one observation during the intervention phase week 1, week 2 and time following week 2. In one instance despite containing sufficient data, the person-specific GAM could not be estimated due to a lack of variance (i.e. habit strength remained constant over time); consequently, rate of change equal to zero was imputed for this participant. See the online repository time series data visualization file for plots of all within-person time series and model predictions (https://osf.io/z7tby/).

Figure S3.4. GAMs (panels a.-d.) and asymptotic models (panels e.-h.) that did not meet set criteria.



Note. Dashed vertical lines (panels a.-d.) indicate the 7th and 14th day of the intervention phase. GAMs were required to contain at least one SRBAI observation during the first week, second week and time following the second week for the rate of change to be calculated for the first and second weeks. Idiographic asymptotic models (panels e.-h.) were deemed invalid estimates if the root-mean-square error was above 0.33 (panel e.), the time series contained a consecutive gap of SRBAI observations longer than 21 days (panels f. and g.), or the trajectory approached an upper asymptote (panel g.); GAMs: generalized additive models.

Table S3.3 | Descriptive statistics of observed habit strength and indicators of habit degradation by allocated group.

Measure	Intervention group	Reward condition	*n*	Mean	*IQR*
Initial observed habit strength	full sample	not applicable	313	2.63	2.25, 3.00
	control	not applicable	50	2.65	2.25, 3.00
	intervention	not applicable	263	2.58	2.00, 3.25
	inhibition	no reward	44	2.50	2.25, 3.00
	inhibition	reward	44	2.84	2.25, 3.31
	substitution	no reward	44	2.63	2.00, 3.00
	substitution	reward	44	2.78	2.50, 3.00
	reduced accessibility	no reward	44	2.67	2.25, 3.25
	reduced accessibility	reward	43	2.45	2.00, 3.00
Final observed habit strength*	full sample	not applicable	313	1.53	0.94, 2.08
	control	not applicable	50	1.69	0.75, 2.50
	intervention	not applicable	263	1.5	0.95, 2.00
	inhibition	no reward	44	1.63	1.00, 2.09
	inhibition	reward	44	1.65	1.00, 2.25
	substitution	no reward	44	1.41	0.59, 2.00
	substitution	reward	44	1.29	0.63, 1.91
	reduced accessibility	no reward	44	1.42	0.87, 2.00
	reduced accessibility	reward	43	1.60	1.00, 2.11
Week 12 average habit strength	full sample	not applicable	178	1.34	0.59, 2.00
	control	not applicable	32	1.65	0.75, 2.27
	intervention	not applicable	146	1.27	0.52, 2.00
	inhibition	no reward	19	1.50	0.75, 2.02
	inhibition	reward	21	1.18	0.35, 2.00
	substitution	no reward	27	1.41	0.56, 2.06
	substitution	reward	27	0.97	0.21, 1.45
	reduced accessibility	no reward	26	1.29	0.64, 1.85
	reduced accessibility	reward	26	1.35	0.93, 1.96
Frequency of reaching and time needed to reach 95% of lower asymptote**	full sample	not applicable	66	21.79	6.25, 27.00
	control	not applicable	12	13.58	1.75, 23.50
	intervention	not applicable	54	23.61	8.25, 31.50
	inhibition	no reward	8	29.50	9.25, 44.25
	inhibition	reward	7	24.71	12.50, 25.50
	substitution	no reward	10	13.90	5.25, 24.00
	substitution	reward	9	26.89	11.00, 26.00
	reduced accessibility	no reward	10	33.00	13.00, 48.25
	reduced accessibility	reward	10	15.50	5.25, 22.25
Week 1 daily average habit strength rate of change	full sample	not applicable	250	-0.07	-0.11, -0.01
	control	not applicable	42	-0.03	-0.07, 0.00
	intervention	not applicable	208	-0.07	-0.12, -0.01
	inhibition	no reward	30	-0.06	-0.10. 0.00
	inhibition	reward	36	-0.07	-0.11, -0.01
	substitution	no reward	38	-0.09	-0.13, -0.01
	substitution	reward	34	-0.09	-0.12, -0.02
	reduced accessibility	no reward	37	-0.08	-0.13, -0.02
	reduced accessibility	reward	33	-0.05	-0.08, -0.01
Week 2 daily average habit strength rate of change	full sample	not applicable	250	-0.03	-0.06, 0.00
	control	not applicable	42	-0.02	-0.02, 0.00
	intervention	not applicable	208	-0.03	-0.06, 0.00
	inhibition	no reward	30	-0.03	-0.07, 0.00
	inhibition	reward	36	-0.03	-0.06, 0.00
	substitution	no reward	38	-0.03	-0.07, 0.00
	substitution	reward	34	-0.04	-0.06, -0.02
	reduced accessibility	no reward	37	-0.05	-0.06, -0.01
	reduced accessibility	reward	33	-0.03	-0.05, 0.00

*Note***.** IQR: Interquartile range (25%, 75%). *Based on the average week 12 habit strength score, or the last available habit strength observation carried forward if no observations were available for week 12; **Frequency depicted with n and time in days depicted with mean and *IQR*.

8.2.3 Main analysis

Concerning the covariate of primary analyses, initial habit strength was a significant covariate of final habit strength in the H1.1 model ($F(1, 310) = 45.10$, $p < .001$, generalized eta squared (*ges*) = .127) and in the H1.2-.3 model ($F(1, 256) = 30.79$, $p < .001$, *ges* = .107). In contrast, initial habit strength was not a significant covariate in model H1.4 ($z(1) = -1.703$, $p = 0.089$, odds ratio = 0.732), model H1.5-.6 ($\chi^2(1) = 2.479$, $p = 0.115$, odds ratio = 0.717), model H2.4 ($F(1, 63) = 1.87$, $p = 0.177$, *ges* = 0.029), or in model H2.5-.6 ($F(1, 47) = 0.07$, $p = 0.787$, *ges* = 0.002).

Table S3.4. Pairwise comparisons from logistic regression results for the likelihood of reaching 95% of the lower asymptote.

Model	Contrast	*OR (SE)*	95% *CI*	*p*
H1.4	control / intervention	1.19 (0.44)	[0.58, 2.45]	0.631
H1.5-H1.6	No reward: reduced accessibility / inhibition*	1.41 (0.75)	[0.40, 4.94]	0.798
	No reward: reduced accessibility / substitution*	1.02 (0.52)	[0.31, 3.38]	0.999
	No reward: inhibition / substitution*	0.72 (0.39)	[0.21, 2.53]	0.817
	Reward: reduced accessibility / inhibition*	1.42 (0.79)	[0.39, 5.22]	0.803
	Reward: reduced accessibility / substitution*	1.05 (0.56)	[0.31, 3.62]	0.995
	Reward: inhibition / substitution*	0.74 (0.42)	[0.20, 2.75]	0.855
	Reduced accessibility: no reward / reward	1.04 (0.54)	[0.38, 2.86]	0.932
	Inhibition: no reward / reward	1.05 (0.61)	[0.34, 3.25]	0.928
	Substitution: no reward / reward	1.08 (0.57)	[0.39, 3.01]	0.882

Note. *OR*: Odds ratio. Odds ratios are estimated marginal means back-transformed from the log odds scale; *CI*: confidence interval. *Confidence intervals and *p*-values adjusted with Tukey methods for comparing a family of 3 estimates.

Table S3.5. Overview of power detection analysis and equivalence tests for each hypothesis using the corresponding smallest effect size of interest.

Outcome; SESOI; ROPE	Hypo-thesis	Comparison	Primary analysis main effect	Power detection for SESOI	Two one-sided test of equivalence	Interpretation of primary analysis null findings
Magnitude of change; SESOI: 0.50; ROPE: [-0.50. 0.50]	H1.1	intervention vs. Control	$F(1, 310) = 2.38$, $p = .124$	85	90% *CI*: [-0.46, 0.02], $p = 0.029$, **equivalence accepted**	**informative null**
	H1.2	substitution vs. inhibition vs. reduced accessibility	$F(2, 256) = 2.68$, $p = .071$	87	Inhibition: 90% *CI*: [-0.04, 0.61], $p = 0.134$, **equivalence undecided**; Substitution: 90% *CI*: [-0.32, 0.33], $p = 0.012$, **equivalence accepted**	**informative null for substitution, otherwise inconclusive**
	H1.3	reward vs. no reward	$F(1, 256) = 0.02$, $p = .892$	98	90% *CI*: [-0.05, 0.60], $p = 0.127$, **equivalence undecided**	**inconclusive**
95% asymptote (reached vs. not reached); SESOI: [0.80, 1.25] odds ratio; ROPE: [-0.22. 0.22]	H1.4	intervention vs. control	$z(1) = 0.480$, $p = 0.631$	10	90% *CI*: [-0.78, 0.43], $p = 0.588$, **equivalence undecided**	**inconclusive**
	H1.5	substitution vs. inhibition vs. reduced accessibility	$\chi^2(2) = 0.518$, $p = 0.772$	7	Inhibition: 90% *CI*: [-1.22, 0.54], $p = 0.734$, **equivalence undecided**; Substitution: 90% *CI*: [-0.86, 0.82], $p = 0.663$, **equivalence undecided**	**inconclusive**
	H1.6	reward vs. no reward	$\chi^2(1) = 0.007$, $p = 0.933$	7	90% *CI*: [-0.89, 0.80], $p = 0.666$, **equivalence undecided**	**inconclusive**

Table S3.5 (continued 1/2). Overview of power detection analysis and equivalence tests for each hypothesis using the corresponding smallest effect size of interest.

Outcome; SESOI; ROPE	Hypo-thesis	Comparison	Primary analysis main effect	Power detection for SESOI	Two one-sided test of equivalence	Interpretation of primary analysis null findings
Average rate of change (week 1); SESOI: 0.034; ROPE: [-0.034. 0.034]	H2.1	intervention vs. control	$F(1, 248) = 7.50$, p_{adj}* = 0.042	56	90% *CI*: [-0.07, -0.02], $p = 0.728$, **equivalence rejected**	n/a (significant difference)
	H2.2	substitution vs. inhibition vs. reduced accessibility	$F(2, 202) = 0.93$, p= 0.395	43	Inhibition: 90% *CI*: [-0.02, 0.06], p = 0.256, **equivalence undecided**; Substitution: 90% *CI*: [-0.04, 0.03], $p = 0.148$, **equivalence undecided**	**inconclusive**
	H2.3	reward vs. no reward	$F(1, 202) = 0.07$, $p = 0.792$	71	90% *CI*: [-0.01, 0.06], $p = 0.333$, **equivalence undecided**	**inconclusive**
Average rate of change (week 2); SESOI: 0.034; ROPE: [-0.034. 0.034]	H2.1	intervention vs. control	$F(1, 248) = 4.33$, p_{adj}* = 0.234	99	90% *CI*: [-0.03, 0.00], $p = 0.007$, **equivalence accepted**	**informative**
	H2.2	substitution vs. inhibition vs. reduced accessibility	$F(2, 202) = 0.42$, $p = 0.655$	99	Inhibition: 90% *CI*: [0.00, 0.04], p = 0.094, **equivalence rejected;** Substitution: 90% *CI*: [0.00, 0.03], p = 0.033, **equivalence accepted**	**informative null for substitution, otherwise inconclusive**
	H2.3	reward vs. no reward	$F(1, 202) = 0.04$, $p = 0.846$	100	90% *CI*: [0.00, 0.04], $p = 0.067$, **equivalence rejected**	**inconclusive**

Table S3.5 (continued 2/2). Overview of power detection analysis and equivalence tests for each hypothesis using the corresponding smallest effect size of interest.

Outcome; SESOI; ROPE	Hypo-thesis	Comparison	Primary analysis main effect	Power detection for SESOI	Two one-sided test of equivalence	Interpretation of primary analysis null findings
Days to reach 95% asymptote; SESOI: 1 day ROPE: see test of equivalence column	H2.4	intervention vs. control	$F(1, 63) = 3.43$, $p = 0.069$	2	ROPE: [-0.17 0.15] 90% *CI*: [0.07, 1.44], $p = 0.938$, **equivalence rejected**	**inconclusive**
	H2.5	substitution vs. inhibition vs. reduced accessibility	$F(2, 47) = 0.17$, $p = 0.848$	6	ROPE: [-0.08 0.07] Inhibition: 90% *CI*: [-1.43, 0.60], $p = 0.923$, **equivalence undecided**; Substitution: 90% *CI*: [-1.84, 0.09], $p = 0.968$, **equivalence undecided**	**inconclusive**
	H2.6	reward vs. no reward	$F(1, 47) = 0.06$, $p = 0.813$	6	ROPE: [-0.08 0.07] 90% *CI*: [-1.84, 0.07], $p = 0.969$, **equivalence undecided**	**inconclusive**

Note. Simulation based power is based on the defined SESOI and observed condition specific sample sizes and standard deviations (alpha = 0.05, simulations n = 10000); SESOI: Smallest effect size of interest; ROPE: Region of practical equivalence; CI: confidence interval; n/a: not applicable; p_{adj}*: adjusted for a family of 6 tests with the sequentially rejective Bonferroni method; Equivalence accepted: The 90% CI is completely within the ROPE; Equivalence rejected: The 90% CI is not completely within the ROPE and the CI does not contain 0. Equivalence undecided: The 90% CI is not completely within the ROPE and the CI contains 0.

8.2.4 Intervention fidelity and manipulation check

Manual coding of strategies used in implementation intentions revealed inconsistent adherence to intervention arm specific guidelines. Specifically, 51% (45/88) of participants assigned to an inhibition strategy group formulated implementation intentions aiming to inhibit habitual unhealthy snacking, and 45% (39/87) of participants assigned to a reduced accessibility strategy group formulated implementation intentions aiming to reduce accessibility of unhealthy snacks. Adherence was higher in the substitution group, where 98% (86/88) participants formulated implementation intentions aiming at replacing habitual unhealthy snacking with an alternative response. When further accounting for participants' self-reported additional strategy use based on post-study survey responses, adherence decreased further. Specifically, when excluding participants who reported usage of unassigned strategies adherence rates were 50% (25 / 50) for the control group, 31% (27 / 88) for inhibition groups, 48% (42 / 88) for substitution groups, and 25% (22 / 87) for reduced accessibility groups (see Supplementary Table S3.5).

Intervention fidelity of reward is first assessed in light of responding frequency to the event-contingent questionnaire, as this served as the trigger for reward delivery. For the entire sample over the course of the study (excluding control group participants) 2,311 cue encounters were recorded across 216 participants (i.e. 47 (18%) intervention group participants never recorded a cue encounter). Event-contingent entries of cue-encounters decreased with time, as 50% (1157 / 2311) of cue encounters were recorded by day 22 of the intervention phase. In 57% (1,324 / 2,311) of cue encounters, no subsequent snacking occurred. In total 158 participants recorded no snacking following a cue encounter at least once, of which 91 participants were in a reward condition (entailing 920 observations). These 920 observations were triggers for reward delivery, but it cannot be confirmed that reward was delivered on all intended occasions. The duration of viewing a reward message was available for 639 observations across 85 participants, for which the mean value was 2.7 seconds (interquartile range: 1.3, 3.3 seconds).

Regarding the manipulation check of reward, perceived reward was evaluated in total 89 times across 49 participants, for which the mean value was 3.3 (median = 4; interquartile range: 3, 4) suggesting high perceived reward. 50% (45 / 89) of perceived reward observations were recorded by day 12 of the intervention phase, and 75% (67 / 89) were recorded by day 30.

8.2.5 Sensitivity analyses

Sensitivity analyses addressing magnitude of change in habit strength (H1.1-.3) broadly supported the primary findings (see Supplementary Table S3.6 for descriptive statistics and Table S3.7 for sensitivity analysis results). However, in one of the four sensitivity analysis comparing intervention and control groups, there was a significant intervention effect when excluding participants without habit strength observations in the final week of the study. Specifically, the magnitude of change was significantly greater in the intervention group compared to control ($F(1, 175) = 4.54$, $p = 0.034$, $ges = 0.025$). However, as this result was not evident in any other analyses conducted, this is not considered worthy of further interpretation. Additionally, when reassignment to actual strategy use was modelled (H1.2-.3), a significant interaction emerged ($F(2, 133) = 3.35$, $p = 0.038$, $ges = 0.048$), suggesting a smaller magnitude of change for the reduced accessibility strategy when combined with reward compared to without reward. This interaction remained significant when additionally excluding participants

without observations during the last week of the study ($F(2, 246) = 3.25$, $p = 0.040$, *ges* = 0.026). Descriptively, this interaction was somewhat visible in the primary analysis as well (see manuscript Figure 13 panel b). However, as these interaction results are based on a small number of participants, it is not considered worthy of further interpretation.

Sensitivity analyses addressing week 1 rate of change supported primary analyses. Firstly, sensitivity analysis using robust ANOVA supported the findings of a significant effect of intervention group status being associated to a faster rate of change compared to the control group for week 1 ($F(1, 49.19) = 8.12$, $p = 0.006$, bootstrap confidence interval (*CI*) = [0.03, 0.58], explanatory measure of effect size = 0.32). Additionally, findings suggesting a faster rate of change in the intervention compared to control group remained significant (Supplementary Table S3.8) when participants were reassigned based on actual strategy use and those with blended strategy use were excluded ($F(1, 98) = 5.65$, $p = 0.019$, *ges* = 0.054). Lastly, in congruence with primary analyses, results concerning comparison of intervention groups (or actual strategy use) and reward condition remained statistically insignificant in sensitivity analysis for week 1 rate of change (Supplementary Table S3.8).

Sensitivity analyses addressing week 2 rate of change findings were less consistent. When comparing intervention and control groups (H2.1), sensitivity analysis using robust ANOVA supported the findings of a significant effect of intervention group status being associated to a faster rate of change compared to the control group for week 2 ($F(1, 40.12) = 7.67$, $p = 0.008$, bootstrap *CI* = [0.03, 0.57], explanatory measure of effect size = 0.33). However, the main effect of intervention group was not replicated (Supplementary Table S3.7) when modelling reassigned actual strategy and excluding blended strategy use ($F(1, 98) = 1.30$, $p = 0.257$, *ges* = 0.013).

When comparing intervention groups and reward condition (H2.2-.3), sensitivity analysis using robust regression supported the findings of a non-significant effect for week 1 and week 2 based on t-values. In the week 1 analysis, the coefficient for reward was the largest in magnitude among predictors ($t(202) = 1.38$, estimate = 0.025, *SE* = 0.02). In the week 2 analysis, the coefficient for the strategy group inhibition was the largest in magnitude among predictors ($t(202) = 1.29$, estimate = 0.013, *SE* = 0.01). In turn sensitivity analyses with reassigned actual strategy and excluding blended strategy use, a significant main effect for strategy ($F(2, 77) = 3.31$, $p = 0.042$, *ges* = 0.079), reward ($F(1, 77) = 6.50$, $p = 0.013$, *ges* = 0.078) and interaction ($F(2, 77) = 7.02$, $p = 0.002$, *ges* = 0.154) emerged (Supplementary Table S3.8). However, as these results are based on a small number of participants and do not replicate in any other analyses conducted, they are not considered worthy of further interpretation.

Table S3.6. Descriptive statistics of variables used in sensitivity analyses

	Overall (N = 313)	Control (n = 50)	Inhibition (n = 44)	Inhibition & reward (n = 44)	Substitution (n = 44)	Substitution & reward (n = 44)	Reduced accessibility (n = 44)	Reduced accessibility & reward (n = 43)
Desirable responding: self-deception enhancement	3.72 (3.33, 4.33)	3.69 (3.33, 4.33)	3.73 (3.33, 4.33)	3.95 (3.33, 4.67)	3.72 (3.33, 4.33)	3.64 (3.17, 4.00)	3.70 (3.33, 4.00)	3.63 (3.33, 4.17)
(missing)	9	0	0	2	1	0	3	3
Desirable responding: impression management	4.27 (3.67, 5.00)	4.19 (3.67, 4.67)	4.36 (3.67, 5.00)	4.25 (3.67, 5.00)	4.36 (3.67, 5.00)	4.55 (4.00, 5.33)	4.11 (3.33, 5.00)	4.06 (3.33, 5.00)
(missing)	8	0	0	2	0	0	3	3
Intention*	3.27 (3.00, 4.00)	3.12 (2.50, 4.00)	3.34 (3.00, 4.00)	3.31 (3.00, 4.00)	3.31 (3.00, 4.00)	3.30 (3.00, 4.00)	3.28 (3.00, 3.75)	3.24 (3.00, 4.00)
Reassigned actual strategy								
Control	50 (17%)	50 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Inhibition	55 (18%)	0 (0%)	21 (48%)	24 (57%)	1 (2.3%)	0 (0%)	5 (13%)	4 (10%)
Substitution	157 (52%)	0 (0%)	21 (48%)	18 (43%)	43 (98%)	43 (100%)	14 (35%)	18 (45%)
Reduced accessibility	41 (14%)	0 (0%)	2 (4.5%)	0 (0%)	0 (0%)	0 (0%)	21 (53%)	18 (45%)
None of above	10	0	0	2	0	1	4	3
Reassigned actual strategy, excluding blended strategy use								
Control	25 (16%)	25 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Inhibition	33 (21%)	0 (0%)	15 (54%)	12 (55%)	1 (4.8%)	0 (0%)	1 (5.3%)	4 (19%)
Substitution	78 (49%)	0 (0%)	13 (46%)	10 (45%)	20 (95%)	22 (100%)	6 (32%)	7 (33%)
Reduced accessibility	22 (14%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	12 (63%)	10 (48%)
None of above / blended	155	25	16	22	23	22	25	22

Note. Desirable responding and intention reported with mean (interquartile range: 25%, 75%); Desirable responding measured with the Balanced Inventory of Desirable Responding (BIDR(Winkler et al., 2006); score range 0-6); *Intention to prevent unhealthy snacking at cue encounter for next 12 weeks. Intention measured on day 7 (score range 0-6); Reassigned strategy reported with n (%).

Table S3.7. Estimated marginal means and test statistics of sensitivity analyses with magnitude of change as outcome (H1.1-.3).

Sensitivity analysis	Intervention group	Reward condition	*n*	Adjusted mean (*SE*)	95% *CI*	Test statistic
H1.1-.3 models: 1. Excluding participants with no SRBAI observations during last week	control	not applicable	32	1.67 (0.17)	[1.33, 2.00]	$F(1, 175) = 4.54$, $p =$ **0.034**, $ges = 0.025$
	intervention	not applicable	146	1.27 (0.08)	[1.11, 1.43]	
	inhibition	no reward	19	1.54 (0.21)	[1.13, 1.96]	Intervention group: $F(2, 139) = 0.79$, $p = 0.454$, $ges = 0.011$ Reward condition: $F(1, 139) = 3.04$, $p = 0.084$, $ges = 0.021$ Interaction: $F(2, 139) = 1.40$, $p = 0.250$, $ges = 0.020$
	inhibition	reward	21	1.12 (0.20)	[0.73, 1.52]	
	substitution	no reward	27	1.39 (0.18)	[1.04, 1.73]	
	substitution	reward	27	0.92 (0.18)	[0.57, 1.27]	
	reduced accessibility	no reward	26	1.32 (0.18)	[0.97, 1.68]	
	reduced accessibility	reward	26	1.41 (0.18)	[1.05, 1.76]	
H1.1-.3 models: 2. Covariates added: intention strength, BMI, and desirable responding	control	not applicable	50	1.67 (0.13)	[1.41, 1.92]	$F(1, 297) = 1.41$, $p = 0.237$, $ges = 0.005$
	intervention	not applicable	254	1.50 (0.06)	[1.38, 1.61]	
	inhibition	no reward	44	1.73 (0.14)	[1.46, 2.00]	Intervention group: $F(2, 243) = 2.35$, $p = 0.098$, $ges = 0.020$ Reward condition: $F(1, 243) = 0.12$, $p = 0.733$, $ges < 0.001$ Interaction: $F(2, 243) = 1.81$, $p = 0.166$, $ges = 0.015$
	inhibition	reward	42	1.51 (0.14)	[1.23, 1.79]	
	substitution	no reward	43	1.41 (0.14)	[1.14, 1.68]	
	substitution	reward	44	1.24 (0.14)	[0.97, 1.51]	
	reduced accessibility	no reward	41	1.40 (0.14)	[1.12, 1.68]	
	reduced accessibility	reward	40	1.67 (0.15)	[1.38, 1.95]	
H1.1-.3 models: 1. & 2. combined	control	not applicable	32	1.51 (0.17)	[1.18, 1.85]	$F(1, 166) = 1.28$, $p = 0.260$, $ges = 0.008$
	intervention	not applicable	141	1.30 (0.08)	[1.14, 1.46]	
	inhibition	no reward	19	1.63 (0.21)	[1.22, 2.05]	Intervention group: $F(2, 130) = 0.38$, $p = 0.684$, $ges = 0.006$ Reward condition: $F(1, 130) = 3.75$, $p = 0.055$, $ges = 0.020$ Interaction: $F(2, 130) = 1.81$, $p = 0.168$, $ges = 0.027$
	inhibition	reward	20	1.02 (0.21)	[0.62, 1.43]	
	substitution	no reward	27	1.38 (0.17)	[1.04, 1.72]	
	substitution	reward	27	0.99 (0.18)	[0.64, 1.34]	
	reduced accessibility	no reward	24	1.27 (0.19)	[0.91, 1.64]	
	reduced accessibility	reward	24	1.38 (0.18)	[1.01, 1.74]	

Table S3.7 (continued). Estimated marginal means and test statistics of sensitivity analyses with magnitude of change as outcome (H1.1-.3).

Sensitivity analysis	Intervention group	Reward condition	*n*	Adjusted mean (*SE*)	95% *CI*	Test statistic
H1.2-.3 model: Reassigned actual strategy group*	inhibition	no reward	27	1.62 (0.18)	[1.27, 1.97]	Strategy group: $F(2, 246) = 0.00$, $p = 0.982$, $ges < 0.001$ Reward condition: $F(1, 246) = 0.39$, $p = 0.535$, $ges = 0.002$ Interaction: $F(2, 246) = 3.25$, $p =$ **0.040**, $ges = 0.026$
	inhibition	reward	28	1.34 (0.18)	[1.00, 1.69]	
	substitution	no reward	78	1.56 (0.11)	[1.35, 1.77]	
	substitution	reward	79	1.46 (0.11)	[1.25, 1.66]	
	reduced accessibility	no reward	23	1.18 (0.19)	[0.80, 1.56]	
	reduced accessibility	reward	18	1.82 (0.22)	[1.39, 2.26]	
H1.2-.3 model: 1. & reassigned actual strategy group*	inhibition	no reward	10	1.47 (0.29)	[0.89, 2.05]	Strategy group: $F(2, 133) = 0.19$, $p = 0.831$, $ges = 0.003$ Reward condition: $F(1, 133) = 0.27$, $p = 0.605$, $ges = 0.002$ Interaction: $F(2, 133) = 3.35$, $p =$ **0.038**, $ges = 0.048$
	inhibition	reward	14	0.91 (0.25)	[0.42, 1.39]	
	substitution	no reward	46	1.50 (0.14)	[1.23, 1.76]	
	substitution	reward	46	1.13 (0.14)	[0.86, 1.39]	
	reduced accessibility	no reward	12	0.93 (0.26)	[0.41, 1.45]	
	reduced accessibility	reward	12	1.57 (0.26)	[1.05, 2.09]	
H1.1-.3 models: 1. & reassigned actual strategy group & excluding blended strategy use	control	not applicable	10	1.86 (0.28)	[1.29, 2.43]	$F(1, 44) = 3.89$, $p = 0.055$, $ges = 0.081$
	intervention	not applicable	37	1.23 (0.15)	[0.94, 1.53]	
	inhibition	no reward	4	1.10 (0.47)	[0.15, 2.06]	Strategy group: $F(2, 30) = 0.19$, $p = 0.829$, $ges = 0.012$ Reward condition: $F(1, 30) = 0.30$, $p = 0.590$, $ges = 0.010$ Interaction: $F(1, 30) = 0.36$, $p = 0.566$, $ges = 0.012$
	inhibition	reward	4	1.08 (0.47)	[0.13, 2.03]	
	substitution	no reward	10	1.41 (0.29)	[0.81, 2.01]	
	substitution	reward	12	1.22 (0.27)	[0.68, 1.77]	
	reduced accessibility	no reward	3	0.80 (0.55)	[-0.32, 1.91]	
	reduced accessibility	reward	4	1.58 (0.46)	[0.63, 2.53]	

Note. *Only reassigning actual strategy use (and not also excluding blended strategy use) cannot be done for control group, because reassignment is based on implementation intentions which control group participants did not formulate; *ges*: generalized eta squared.

Table S3.8. Estimated marginal means and test statistics of sensitivity analyses with rate of change as outcome (H2.1-.3).

Sensitivity analysis	Intervention group	Reward condition	*n*	Adjusted mean (*SE*)	95% *CI*	Test statistic
H2.1-.3 models: Reassigned actual strategy group & excluding blended strategy use Week 1	control	not applicable	17	-0.02 (0.02)	[-0.07, 0.03]	$F(1, 98) = 5.65$, $p =$ **0.019**, *ges* = 0.054
	intervention	not applicable	83	-0.08 (0.01)	[-0.10, -0.06]	
	inhibition	no reward	9	-0.09 (0.03)	[-0.16, -0.02]	Strategy group: $F(2, 77) = 0.05$, $p = 0.951$, *ges* = 0.001 Reward condition: $F(1, 77) = 2.81$, $p =$ 0.097, *ges* = 0.035 Interaction: $F(2, 77) = 2.06$, $p = 0.134$, *ges* = 0.058
	inhibition	reward	10	-0.06 (0.03)	[-0.13, 0.00]	
	substitution	no reward	26	-0.07 (0.02)	[-0.11, -0.03]	
	substitution	reward	25	-0.09 (0.02)	[-0.13, -0.04]	
	reduced accessibility	no reward	7	-0.15 (0.04)	[-0.23, -0.07]	
	reduced accessibility	reward	6	-0.03 (0.04)	[-0.11, 0.06]	
H2.1-.3 models: Reassigned actual strategy group & excluding blended strategy use Week 2	control	not applicable	17	-0.02 (0.01)	[-0.04, 0.00]	$F(1, 98) = 1.30$, $p = 0.257$, *ges* = 0.013
	intervention	not applicable	83	-0.03 (0.01)	[-0.04, -0.02]	
	inhibition	no reward	9	-0.03 (0.01)	[-0.06, -0.01]	Strategy group: $F(2, 77) = 3.31$, $p =$ **0.042**, *ges* = 0.079 Reward condition: $F(1, 77) = 6.50$, $p =$ **0.013**, *ges* = 0.078 Interaction: $F(2, 77) = 7.02$, $p =$ **0.002**, *ges* = 0.154
	inhibition	reward	10	-0.02 (0.01)	[-0.04, 0.00]	
	substitution	no reward	26	-0.02 (0.01)	[-0.04, -0.01]	
	substitution	reward	25	-0.04 (0.01)	[-0.05, -0.02]	
	reduced accessibility	no reward	7	-0.10 (0.01)	[-0.13, -0.07]	
	reduced accessibility	reward	6	-0.02 (0.02)	[-0.05, 0.01]	
H2.2-.3 week 1 model: intention strength covariate added*	inhibition	no reward	30	-0.06 (0.02)	[-0.09, -0.02]	Intervention group: $F(2, 201) = 1.09$, $p =$ 0.337, *ges* = 0.011 Reward condition: $F(1, 201) = 0.05$, $p =$ 0.835, *ges* < 0.001 Interaction: $F(2, 201) = 0.97$, $p = 0.382$, *ges* = 0.010
	inhibition	reward	36	-0.08 (0.02)	[-0.11, -0.05]	
	substitution	no reward	38	-0.09 (0.02)	[-0.12, -0.06]	
	substitution	reward	34	-0.09 (0.02)	[-0.12, -0.05]	
	reduced accessibility	no reward	37	-0.08 (0.02)	[-0.11, -0.05]	
	reduced accessibility	reward	33	-0.05 (0.02)	[-0.09, -0.02]	
H2.2-.3 week 2 model: intention strength covariate added*	inhibition	no reward	30	-0.02 (0.01)	[-0.04, -0.01]	Intervention group: $F(2, 201) = 0.56$, $p =$ 0.571, *ges* = 0.006 Reward condition: $F(1, 201) = 0.02$, $p =$ 0.891, *ges* < 0.001 Interaction: $F(2, 201) = 2.42$, $p = 0.091$, *ges* = 0.024
	inhibition	reward	36	-0.03 (0.01)	[-0.05, -0.02]	
	substitution	no reward	38	-0.03 (0.01)	[-0.04, -0.02]	
	substitution	reward	34	-0.04 (0.01)	[-0.05, -0.02]	
	reduced accessibility	no reward	37	-0.05 (0.01)	[-0.06, -0.03]	
	reduced accessibility	reward	33	-0.03 (0.01)	[-0.04, -0.01]	

Note. *Sensitivity analysis conducted to account for missingness pattern identified; *ges*: generalized eta squared.

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