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The Role of Habit Strength in Complex Health Behaviors and Its Determinants in Real Life Settings

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Abstract

Long-term maintenance of positive health-related behaviors is key in the prevention, management, and rehabilitation of chronic conditions, such as cardiovascular diseases, diabetes and cancer. Habits, i.e., context-response associations where the context automatically triggers a behavioral impulse, are proposed to facilitate behavioral maintenance by guiding behavior despite low intentions (de Bruijn & Rhodes, 2011). However, findings on the interplay between habit and intention strength remain inconclusive due to methodological limitations, and little is understood about how habit interacts with volitional processes, such as spontaneous action planning. Supporting successful habit formation requires an understanding of determinants that facilitate learning of context-response links. Habits are assumed to form more quickly if the behavior is intrinsically rewarding (de Wit & Dickinson, 2009), but study designs that are able to capture reward in the critical moment are lacking. Aside from intrinsic reward, few theoretical determinants have been tested that may be linked to habit strength beyond behavioral repetition. Moreover, unwanted habits present a barrier for behavior change (Gardner et al., 2021) and opposing assumptions exist on whether old habits persist or decay, when substituted with a new habitual response (Mercuur, 2021). These propositions warrant investigation in real-life settings where participants are supported to substitute unwanted habits with healthier alternatives.

The present thesis examined the role of habit in complex health behaviors and its determinants in real life settings. Specifically, the following research questions were addressed: **RQ 1:** How do reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding complex health behavior? (*Study 1*). ***RQ 2:*** How do habits form over time and what factors facilitate habit formation in real-life settings? (*Study 2 and 3*). ***RQ 3:*** How do habits decay over time and what factors facilitate habit decay in real-life settings? (*Study 3*).

The empirical findings of this thesis are based on three data sets. The first study is a secondary analysis of data from 225 participants in a planning intervention that targeted increase of daily physical activity. The participants self-reported their intention strength, spontaneous action planning, and habit strength at five measurement follow-ups over a one-year period. The second study is a secondary analysis of data from 135 participants in an online planning intervention that aimed at forming a healthy nutrition habit. The participants reported habit strength and theoretical determinants daily over 12 weeks. The third study is a primary analysis of data from 42 participants in an online planning intervention that targeted substitution of an old with a new, more active commuting habit. The participants provided multiple daily assessments during a baseline week and five post-intervention weeks, spanning 14 weeks. Participants reported daily habit strength, experienced reward and regret, and weekly plan enactment for both new and old commuting behaviors. In all studies multilevel models were fit.

Based on the empirical findings of this thesis, the research questions 1-3 can be answered as follows: **RQ 1)** Strong habits seem to compensate lowered intention strength when guiding complex health behavior. However, spontaneous action planning remains an important reflective process for behavioral engagement independent of habit strength. **RQ 2)** In the context of habit formation and substitution, habit strength increases more quickly in earlier phases whereas the increase is less pronounced in later phases. Every opportunity to engage in the new behavior seems important when substituting habits. Moreover, experienced reward upon behavioral performance, captured through momentary assessments, is associated with higher habit strength, whereas more distal affective judgments may not reflect the reward directly linked to habit strength. Additionally, the findings suggest that higher than usual alignment between reflective processes and habit is associated with more automatic behavioral performance on a given day and a certain degree of average alignment of reflective processes and habit seems to be a pre-requisite for healthy habits to form. **RQ 3)** When substituted with a healthier alternative, old habit strength decays linearly but only in part. The decay of old habit strength is associated with consistently performing the new, desired behavior in the old context. Moreover, immediate negative experiences of the old behavior seem to be associated with habit decay.

Future research is needed to further examine how determinants of habit change can be manipulated in habit interventions to facilitate habit formation and habit decay.

Zusammenfassung

Die langfristige Aufrechterhaltung von positiven Gesundheitsverhaltensweisen ist entscheidend für die Prävention, das Management und die Rehabilitation chronischer Erkrankungen, wie beispielsweise Herz-Kreislauf-Erkrankungen, Diabetes und Krebs. Es wird angenommen, dass Gewohnheiten – d.h. Assoziationen zwischen Kontext und Reaktion, bei denen der Kontext automatisch einen Verhaltensimpuls auslöst – die Aufrechterhaltung von Verhalten erleichtern, indem sie das Verhalten trotz geringer Intentionsstärke steuern (de Bruijn & Rhodes, 2011). Ergebnisse zur Interaktion von Gewohnheit und Intentionsstärke bei der Steuerung komplexer Gesundheitsverhaltensweisen blieben allerdings aufgrund methodischer Einschränkungen uneindeutig. Über das Zusammenspiel von Gewohnheiten und volitionaler Prozesse, wie beispielsweise spontaner Handlungsplanung, ist insgesamt noch wenig bekannt. Um eine erfolgreiche Gewohnheitsbildung zu unterstützen, ist es notwendig, deren theoretische Determinanten zu verstehen. Es wird angenommen, dass Gewohnheiten schneller gebildet werden, wenn das Verhalten als intrinsisch belohnend erlebt wird (de Wit & Dickinson, 2009). Allerdings fehlt es an Studiendesigns, die in der Lage sind die intrinsische Belohnung im entscheidenden Moment zu erfassen. Abgesehen von intrinsischer Belohnung wurden bislang nur wenige theoretische Determinanten getestet, die mit der Gewohnheitsstärke über die Wiederholung von Verhalten hinaus assoziiert sind. Zudem können unerwünschte Gewohnheiten ein Hindernis für Verhaltensänderungen darstellen (Gardner et al., 2021). Es existieren gegensätzliche Annahmen darüber, ob alte Gewohnheiten bestehen bleiben oder sich auflösen, wenn sie durch ein neues Verhalten im selben Kontext ersetzt werden (Mercuur, 2021). Die Überprüfung dieser Annahmen erfordert Studien in realen Lebenskontexten, in denen Teilnehmende unterstützt werden, unerwünschte Gewohnheiten durch gesündere Gewohnheiten zu ersetzen.

Die vorliegende Dissertation untersuchte die Rolle von Gewohnheitsstärke bei komplexen Gesundheitsverhalten und deren Determinanten in realen Lebenskontexten. Es wurden folgende Forschungsfragen adressiert: **RQ 1**: Wie interagieren reflektive Faktoren (d. h. Intentionsstärke und spontane Handlungsplanung) und Gewohnheiten bei der Steuerung komplexer

Gesundheitsverhaltensweisen? (*Studie 1*). **RQ 2**: Wie bilden sich Gewohnheiten im Laufe der Zeit und welche Faktoren fördern die Gewohnheitsbildung in realen Lebenskontexten? (*Studien 2 und 3*). **RQ 3**: Wie nehmen Gewohnheiten im Laufe der Zeit ab und welche Faktoren fördern diese Abnahme in realen Lebenskontexten? (*Studie 3*).

Basierend auf den empirischen Ergebnissen dieser Arbeit können die Forschungsfragen 1-3 wie folgt beantwortet werden: **RQ 1**: Starke Gewohnheiten scheinen bei der Steuerung komplexer Gesundheitsverhaltensweisen schwache Intentionen zu kompensieren. Spontane Handlungsplanung bleibt jedoch ein wichtiger reflektiver Faktor für die Verhaltensausführung, unabhängig von der Gewohnheitsstärke. **RQ 2**: Im Kontext der Gewohnheitsbildung und -substitution nimmt die Gewohnheitsstärke in den frühen Phasen schneller zu, während der Anstieg in späteren Phasen weniger ausgeprägt ist. Jede Gelegenheit, das neue Verhalten auszuführen, scheint bei der Substitution von Gewohnheiten wichtig zu sein. Darüber hinaus ist die beim Verhalten erlebte Belohnung, die im Moment der Verhaltensausführung erfasst wird, mit einer höheren Gewohnheitsstärke assoziiert, während distale affektive Bewertungen nicht die Belohnung widerzuspiegeln scheinen, die direkt mit der Gewohnheitsstärke verbunden ist. Die Ergebnisse deuten zudem darauf hin, dass eine stärkere Übereinstimmung als gewöhnlich zwischen reflektiven Faktoren und Gewohnheiten mit einer automatischeren Verhaltensausführung an einem bestimmten Tag verbunden ist und ein gewisses Maß an durchschnittlicher Übereinstimmung zwischen reflektiven Faktoren und Gewohnheiten eine Voraussetzung für die Bildung gesunder Gewohnheiten ist. **RQ 3**: Wird eine alte Gewohnheit durch eine gesündere Alternative ersetzt, nimmt die Stärke der alten Gewohnheit linear und nur teilweise ab. Der Abbau der alten Gewohnheitsstärke ist mit einer konsistenten Ausführung des neuen, gewünschten Verhaltens im alten Kontext verbunden. Darüber hinaus scheinen unmittelbare negative Erfahrungen mit dem alten Verhalten mit dem Abbau von alten Gewohnheiten zusammenzuhängen.

Zukünftige Forschung ist erforderlich, um zu untersuchen, wie Determinanten von Gewohnheitsstärke in Interventionen manipuliert werden können, um die Gewohnheitsbildung und den Gewohnheitsabbau zu fördern.

Chapter 1:
General Introduction

General Introduction

Regular engagement in healthy behaviors, such as physical activity and a healthy diet, prevents non-communicable diseases, promotes longevity and well-being (Dominguez et al., 2021; Hu et al., 2024). However, a vast majority of adults worldwide fails to incorporate physical activity and a healthy diet into daily life (Guthold et al., 2018; Richter et al., 2024). In Western, high-income countries, for example, only approximately one-third of adults meets recommended physical activity levels (Guthold et al., 2018) and most adults fail to meet recommended fruit and vegetable intake while consuming excessive amounts of energy (Richter et al., 2024). In the last decades, health psychological research has identified important reflective processes, such as motivation and volition, that guide adoption and maintenance of health behaviors (Fishbein & Ajzen, 1975; Bandura, 1998; Schwarzer, 2008). Although behavior change interventions that leveraged reflective processes showed promising results for early adoption of health behaviors, maintenance of initial improvements was largely insufficient (Anderson et al., 2001; McEwan et al., 2020). Sustaining short-term behavioral gains requires long-term interventions that protect individuals from motivational and volitional lapses, which are likely to occur when the intervention period ends (Jeffery et al., 2000; McEwan et al., 2020).

Forming healthy habits yields conceivable potential for long-term maintenance of health behaviors. Habits refer to learned context-response associations, where a context or contextual element automatically triggers the associated behavioral response (Gardner & Lally, 2013). Habitual behaviors are characterized by a high efficiency and resistance to change (Gardner & Lally, 2018). At the same time, unwanted habits present a barrier for successful behavior change (Gardner et al., 2021). Where unwanted context-response links (i.e., unwanted habits) persist, individuals are more prone to relapse into old behavioral patterns (Gardner et al., 2021). Physical activity and healthy nutrition behaviors (i.e., health behaviors examined in this thesis) are considered more complex health behaviors, as they involve multiple sub-actions (e.g., meal planning, grocery shopping, cooking) and are characterized by more distal than proximal rewards (e.g., the exhaustion from a workout may be unpleasant but contributes to physical well-being in the long-term; Mullan &

Novoradovskaya, 2018). Complex health behaviors are probably never fully habitual but can involve sub-actions that are initiated by contextual elements (Mullan & Novoradovskaya, 2018).

Understanding the role of habit in complex health behaviors and its determinants in real life settings can inform intervention development for sustained health behavior change. In recent decades, significant progress has been made in habit research with valuable contributions from neuroscience, learning paradigms, and social psychology enhancing theoretical understanding of habit (Verplanken et al., 2018). However, the role of habit in guiding complex health behaviors and its determinants in real-world contexts is not yet fully understood (Gardner et al., 2020). Studies examining how reflective processes (e.g., intention) interact with automatic processes like habit require replication using longitudinal designs that capture variation in motivation within-person (Gardner et al., 2020) and expansion to further types of reflective processes (e.g., spontaneous action planning). Additionally, research on the determinants of habit change has primarily focused on between-person analysis. However, to examine more proximal determinants of changes in habit strength within individuals, event-based measures in longitudinal study designs are needed (Kwasnicka et al., 2018). So far, habit decay has been solely examined in computational simulation studies and requires replication in real-life settings (Mercuur, 2021).

Therefore, the primary objectives of the present thesis were to examine how reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding complex health behavior; describe change trajectories of habit formation and examine its determinants; and describe change trajectories of habit decay and examine its determinants.

The following sections of this chapter review previous theoretical frameworks, empirical findings, and methodological considerations in habit research. Then, the research questions are derived from integrating this literature. Finally, the study projects that were used to empirically investigate these research questions are briefly described.

Reflective and Automatic Drivers of Health Behavior

Well established theories on health behavior change have largely emphasized reflective processes, such as motivation and self-regulation, to change behavior (e.g., Ajzen, 1991; Bandura, 1998; Prochaska & DiClemente, 1983; Schwarzer, 2008). However, findings from meta-analyses on the effectiveness of health behavior change interventions suggest that changing reflective processes does not guarantee health behavior change (Sheeran et al., 2014; Webb & Sheeran, 2006). In recent years, health psychological research showed increasing interest in automatic processes as drivers of health behavior (Hagger, 2016; Sheeran et al., 2013). Dual process models propose that behavior is guided by two distinct, yet interacting types of processes: reflective processes (i.e., goal-directed) and automatic processes (i.e., goal-independent; Evans & Frankish, 2009; Strack & Deutsch, 2004).

Reflective processes are comparatively slow, controllable and guide behavior based on conscious deliberation, such as rational reasoning or assessments of value and anticipation of consequences of an action (Wood & Neal, 2007). For instance, a person intends to go running because physical health is of personal value for that person. The person may then plan to go running the next day, retrieve this intention from memory the next day, resist the urge to watch TV instead, consciously put on running clothes, and so forth. This is a flexible, yet effortful process that requires cognitive capacity and multiple factors to work in unison.

In contrast, automatic processes are comparatively fast, uncontrollable and guide behavior based on associations. Habit is one type of automatic process, where the perceptual input of contextual elements automatically activates a behavioral response (Strack & Deutsch, 2004; Wood & Neal, 2007). For instance, arriving home from work (i.e., context) could automatically trigger the impulse to put on running clothes and leave the house (i.e., response). Thus, *habit strength* refers to the strength of mental context-response associations formed through repeated co-activation of context and response (i.e., context-dependent repetition; Gardner et al, 2015). Any contextual element, such as a location, time of the day, another person, a preceding or subsequent action that repeatedly coincides with a behavior upon context-dependent repetition can develop into a habit relevant context or contextual element (Wood et al., 2022). Initially, basically all health behaviors are performed intentionally, with the aim of achieving a personal goal or a desired outcome. As an intentional behavior is repeated in a stable context, that context becomes associated with the behavior. Consequently, merely perceiving or encountering the context can trigger the associated behavior independent from any goal representation (Wood & Neal, 2007). For example, a person who repeatedly chose to stand up while riding the subway to work may at one point automatically do so upon entering the subway.

Behavioral automaticity is considered the hallmark feature of habitual behavior. Behavioral automaticity reflects the level of efficiency (i.e., requiring minimal attention or cognitive resources), lack of awareness (i.e., occurring without conscious deliberation), goal-independence (i.e., operating independently of intentions), and uncontrollability (i.e., execution without conscious regulation) with which a habitual behavior is being performed (Bargh, 1994). Behavioral automaticity is typically assessed using the Self-Reported Behavioral Automaticity Index (SRBAI, Gardner et al., 2012) and serves as an indicator of habit strength, i.e., the strength of the underlying context-response association. That is, the stronger the association between context and response, the more automatically the habitual behavior should to be performed (Verplanken & Orbell, 2003). This operationalization also allows for the distinction of frequent intentional behaviors (i.e., low behavioral automaticity) and frequent habitual behaviors (i.e., high behavioral automaticity; Gardner et al., 2012).

Habit in Complex Health Behaviors

The question of whether complex health behaviors can truly be governed by simple context-response associations remains a topic of considerable debate (Phillips, 2020). Phillips and Mullan (2023) propose that behavioral complexity increases with the number of sub-actions and amount of time that is required to prepare and perform a behavior. For instance, cooking a healthy meal includes multiple sub-actions (e.g., planning, shopping, preparing, cooking) that take considerable time and is therefore unlikely to be performed without any awareness (Phillips et al., 2016). Health behaviors, such as healthy nutrition behavior and physical activity, are therefore likely guided by both, reflective processes as well as habit (Holland et al., 2016). That is, for example, reaching for potato chips while watching TV may occur habitually, triggered by the context, while buying the chips and placing them on the table may be consciously planned actions. Accordingly, habit strength is rather conceived on a continuum that ranges from fully automatic context-response sequences to non-automatic responses, depending on how many and how strongly sub-actions are performed automatically (Moors & De Houwer, 2006).

The distinction of habitual behavior into two main stages: ‘*habitual instigation*’ - the automatic decision or commitment for a certain behavior - and ‘*habitual execution*’ - the extent to which sub actions are automatically executed - helps to sharpen the role of habit in complex health behaviors that involve multiple sub-actions and distal rewards (Gardner et al., 2016). For example, the decision to go swimming might initially require effortful information processing, such as weighing the pros and cons or planning. However, as instigation becomes more habitual, the individual is assumed to arrive at a decision more automatically (Gardner et al., 2016). Meanwhile, behavioral execution may still involve conscious decision-making, like choosing a swimming lane or varying training routines, indicating non-habitual execution.

Interaction of Reflective Processes and Habit in Guiding Health Behavior

Whether behavior is guided by habit or reflective processes, depends on the habit strength and on the resources available for reflective processes. That is, metaphorically, the interplay of habit and reflective processes is compared to a horse race where habit and reflective processes compete to be translated into behavior (Landis et al., 1978; Neal et al., 2012). In consistent and familiar settings, established habits are expected to win the race by producing behavioral impulses in response to contextual elements more rapidly and effectively than do reflective processes whereas intentional processes dominate in more varying settings (Adriaanse et al., 2011). Moreover, behavior is assumed to be more likely guided by habit when resources for reflective processes are diminished, like in times of ego-depletion, fatigue, distraction, or stress (Wood et al., 2022)

Habit and Intention. Behavioral intentions, as part of the reflective system, refer to the conscious motivation to engage in a specific behavior (Sniehotta et al., 2005). Intentions can vary in their direction (i.e., whether someone intends to perform a behavior or not) and strength (i.e., how strongly a behavior is intended; Rhodes & Rebar, 2017).

The *habit-intention interaction hypothesis*, rooted in dual-process models of behavior, posits that habit and intention interact in guiding behavior (Triandis, 1977; Neal et al., 2012). That is, as habit strength increases, the link between intentions and behavior should weaken, to the point where well-established habits are assumed to override intentions – independent of their direction or strength – altogether. This assumption has different implications depending on whether habitual responses conflict with or align with intended actions (Gardner et al., 2020).

When habit and intention conflict, the habit-intention interaction hypothesis originally proposed that behavior should be more likely follow the habitual impulse, regardless of what type of behavior was intended (Triandis, 1977). For example, someone might habitually grab a snack in the kitchen despite intending not to snack in the kitchen. However, more recently it has been assumed, that although counter-intentional habits might cause single or temporary deviations from intended actions (i.e., action slips; Reason, 1990), reflective processes should dominate over habitual impulses in the longer-term (Gardner et al., 2024; Bouton, 2024). Nevertheless, established, counter-intentional habits present a barrier for health behavior change, given, that habitually triggered action slips might initiate more complex reflective processes, which ultimately result in a prolonged relapse into old behavioral patterns (Gardner et al., 2024; Ten Broeke & Adriaanse, 2023).

When habit and intention align, the habit-intention interaction hypothesis posits that habits can facilitate the realization of intentions, independent of their momentary strength (Gardner et al., 2020). For example, a person who consistently intends to take a 30-minute walk after dinner and has established this as a habit is likely to start walking after dinner automatically, even on days with weaker intention. In such cases, habits may compensate for motivational deficits, supporting the maintenance of healthy behaviors over time. This potential makes the formation of healthy habits an appealing strategy for promoting long-term behavior change and will therefore be further examined in greater detail in this thesis.

A systematic review found the existing empirical evidence on the habit-intention interaction hypothesis when habits and intentions align to be inconclusive (Gardner et al., 2020). The authors assumed that mixed results might stem from methodological limitations, given, that prior studies often used single measures of intentions, failing to capture the typical fluctuation of intention strength within persons over time (Gardner et al., 2020).

Habit and Action Planning. To form an action plan is the most commonly used technique in habit-focused interventions (e.g., Judah et al., 2013; Phillips et al., 2019), where participants are instructed to define in which context (i.e., where or when) they plan to perform an intended behavior (i.e., how or what; Gollwitzer, 1999). Action planning was demonstrated to be an effective volitional strategy, that helps to translate intentions into action (Carraro & Gaudreau, 2014; Sniehotta et al., 2005). Forming an action plan is proposed to mentally tie a context to a behavioral response (Gollwitzer, 1999). Upon frequent repetition, individuals are assumed to internalize these context–behavior associations and behavioral control is supposed to shift to contextual elements that become sufficient to prompt an automatic response (Gardner et al., 2011).

In addition to being used as a behavior change technique in interventions, action planning is also performed spontaneously by individuals in their everyday live. Spontaneous action planning refers to the frequency to which individuals create action plans spontaneously in their daily lives (Carraro & Gaudreau, 2014). It is conceivable that spontaneous action planning becomes superfluous when habit strength is high, particularly if identical action plans are consistently formulated and executed. However, complex health behaviors involve multiple sub-actions, not all of which are likely to become automated. As argued by Hagger and colleagues (2016), the decision to engage in a behavior might be automatically triggered by context cues, but behavioral engagement may involve at least some sub-actions that necessitate reflective processing, such as action planning (Hagger et al., 2016).

Habit Formation

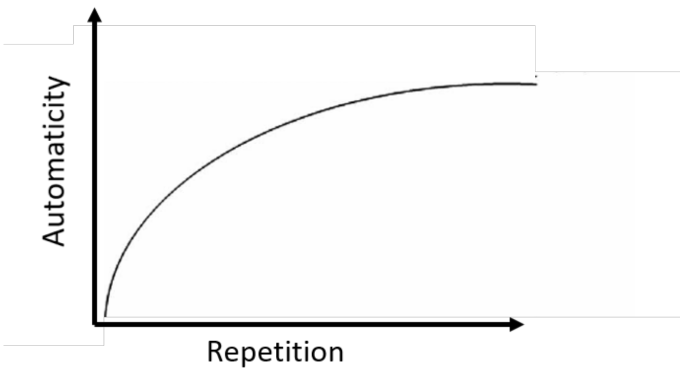
Effectively supporting individuals in building healthy habits requires an understanding of how habits form. First and foremost, context-dependent repetition is assumed to shift behavioral control from more goal-directed to more context-driven behavior (Lally & Gardner, 2013). That is, initially, context-dependent repetition is thought to be driven by reflective processes, such as intention and action planning. With each repetition, mental context-response associations are expected to strengthen and become more deeply embedded within the automatic system, thereby increasing the likelihood that the context will trigger the learned behavior automatically, without requiring reflective processing (Strack & Deutsch, 2004).

Trajectories of Habit Formation

When forming habits, automaticity levels are assumed to increase more rapidly upon earlier repetitions – to a lesser extent with each repetition – eventually reaching a plateau (i.e., relative maximum) where automaticity does not further grow upon behavioral repetitions (see Figure 1.1; Hull, 1943, 1951).

Figure 1.1

Successful Habit Formation.



Prior intensive longitudinal studies that examined the "shape" of habit formation trajectories have generally observed a pattern of rapid initial increases in habit strength that then leveled off over time (e.g., van der Weiden et al., 2020). However, these studies also demonstrated habit formation as a highly individual process, with substantial variation within- and between individuals (e.g., Keller et al., 2021). That is, for instance, among some participants habit strength followed the typical asymptotic curve (e.g., Keller et al., 2021; Lally et al., 2013), while for others, habit strength declined or remained stable over the study period (Keller et al., 2021; van der Weiden et al., 2020).

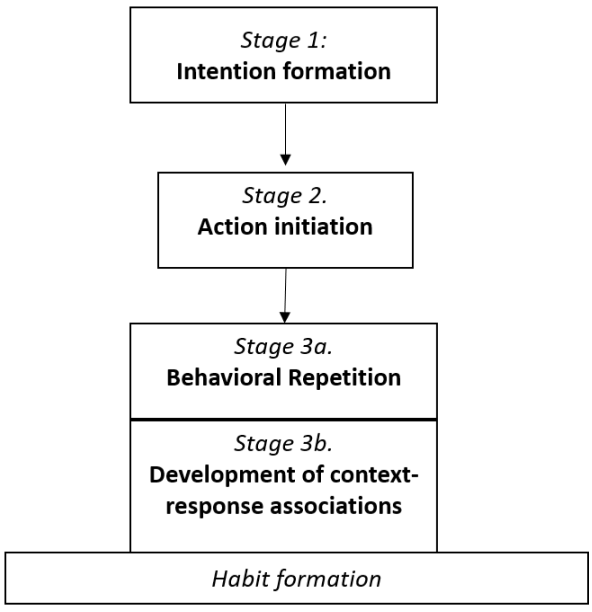
The findings demonstrate that habits form at different speeds and that the achieved maximum levels of habit strength differ substantially across participants even if behavioral frequency is controlled for (Lally et al., 2010). This suggests that additional factors are at play when learning context-response links upon behavioral repetition (Verplanken, 2006).

Determinants of Habit Formation

The framework of habit formation (Figure 1.2, Gardner & Lally, 2018) posits that theoretical determinants of habit formation can be distinguished depending on the stage of behavioral adoption. Stage 1 represents the phase of intention formation, where determinants influencing the decision or intention to act—such as risk perception or outcome expectancies (i.e., motivational determinants)—are at play. Stage 2 involves translating the decision into behavior, where determinants that support goal pursuit, such as action planning or self-monitoring (i.e., volitional determinants) are relevant. Stage 3a pertains to determinants critical for behavioral maintenance, including sustained motivation or volition, while stage 3b involves determinants that facilitate the learning of context-response links upon behavioral performance (Gardner & Lally, 2018; Schwarzer, 2008).

Figure 1.2

A Framework for Understanding Habit Formation and its Determinants



Note. After Gardner & Lally (2018, p. 211).

Echoing extant stage models of behavior change, variables involved in stage 1 to stage 3a have been widely studied and are assumed to boost habit strength through increased behavioral frequency (Gardner & Lally, 2018). Determinants that facilitate the learning of the context-response link (stage 3b) and therefore increase habit strength over and above the mere repetition of behavior are, however, less well understood (Gardner & Lally, 2018).

The following section presents theoretical considerations and prior empirical findings on theoretical determinants of habit formation.

Context Characteristics. Research suggests that certain contexts are particularly conducive for habit formation. That is, for example, performing a stretching exercise in the morning versus in the evening, sped up habit formation due to increased morning cortisol levels in the morning (Fournier et al., 2017) or using preceding (versus subsequent) daily routines as context cues supported formation of a flossing habit (Judah et al., 2013). No difference in habit formation of healthy nutrition habits was found between participants who planned to perform the behavior in response to a time-based versus routine-based context (Keller et al., 2021). The authors noted, however, that time-based contexts often align with existing routines, which might have served as the actual trigger for the novel healthy nutrition behavior (Keller et al., 2021).

Intrinsic Reward. In addition to context characteristics, behavior-related intrinsic reward is assumed to facilitate the learning of context-response links upon behavioral execution (Wood & Neal, 2007). Intrinsic reward is proposed to play multiple roles when forming a habit (Lally & Gardner, 2013). First, individuals hold more stable intentions and thus engage more frequently in behaviors that are intrinsically rewarding (i.e., stage 1-3a; Gardner & Lally, 2018; Keer et al., 2013). Second, intrinsic reward is proposed to directly strengthen context–behavior relationships upon behavioral repetition (i.e., stage 3; Gardner & Lally, 2018). Prior studies demonstrated, for instance, that behavioral repetition of fruit and vegetable consumption (Wiedemann et al., 2014), Vitamin C intake, and flossing (Judah et al., 2018) were linked to habit strength particularly among participants who reported higher intrinsic reward compared to other participants (Judah et al., 2018; Wiedemann et al., 2014).

However, a study conducted by Weyland et al. (2020) could not replicate this finding for the within-person level: higher than usual intrinsic reward (i.e., operationalized as positive valence of affect) was unrelated with instigation habit strength for gym class attendance (Weyland et al., 2020). In a similar vein, within-person intrinsic reward of eating a healthy meal was unrelated to habit strength the next day when participants attempted to form a healthy nutrition habit (Kilb & Labudeck, 2022).

Reflective Processes. In addition, reflective processes may play a role in the automatic performance of behavior. In the process of forming new habits, behaviors are usually guided by the interaction between the reflective and automatic systems. When content of both systems aligns (e.g., the kitchen triggers the impulse to drink water, which matches the goal to stay hydrated and the belief that drinking water is beneficial for health), cognitive demand decreases and behavior should be performed more fluently (Strack & Deutsch, 2014; Winkielman & Cacioppo, 2001). However, conflicting processes of the reflective and automatic system trigger deliberation, which in turn inhibits automatic execution (Strack & Deutsch, 2004). Reflective processes that bind individuals to their intentions (e.g., anticipated regret) and support ease of behavioral execution (e.g., self-efficacy) should therefore be associated with increased behavioral automaticity.

Anticipated Regret. Anticipated regret strengthens intentions and prompts behavioral execution (Brewer et al., 2016; Ellis et al., 2018). Just as people are more likely to engage in behaviors associated with positive emotions, they are also more likely to choose behaviors that help them to avoid negative emotions, such as self-blame or guilt that are expected to arise due to the regret of inaction (Pieters & Zeelenberg, 2007; Zeelenberg & Pieters, 2007). That is, for example, when choosing between going for an evening run or watching television, people often rely on internal representations of potential outcomes (e.g., anticipated regret of not going for a run). Unstable intentions about maintaining a regular exercise routine are likely to trigger reflective processing (e.g., weighing pros and cons) before ultimately deciding to exercise.

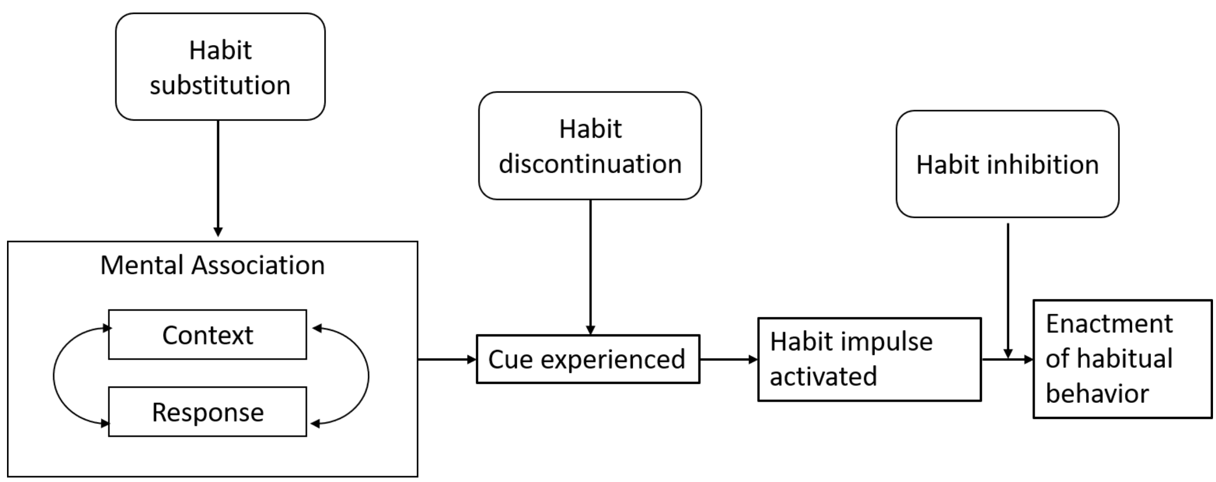
Self-Efficacy. Similarly, self-efficacy strengthens intention and facilitates the translation of intentions into action (Breland et al., 2020; Higgins et al., 2014). Self-efficacy refers to individuals' beliefs on whether they possess the capabilities to exercise control over a particular task (Bandura, 1997) and addresses components that facilitate smooth behavioral execution (e.g., confidence, readiness, commitment, skill) and may therefore drive behavior to a more automatic level. Likewise, low self-efficacy could trigger reflective processing (e.g., anxiety) and therefore disrupt behavioral fluency (Pirolli, 2016; Wang et al., 2013). Prior studies showed that self-efficacy correlated with habit strength of oral hygiene behavior as well as medication intake (Raison et al., 2020; Bolman et al., 2011).

Habit Decay

The persistence of old, unwanted habits increases the risk to relapse into unwanted habitual behaviors (Gardner et al., 2021). To disrupt or dis-continue habitual behaviors, individuals may either deliberately suppress the impulse to act (i.e., habit inhibition), avoid the contexts and cues that potentially trigger the old behavior (i.e., habit discontinuation), or establish new, alternative habitual responses in the same context (i.e., habit substitution; see Figure 1.3, Gardner et al., 2021). The interruption of habitual behavior, however, does not necessarily unlink underlying context-response associations (Walker et al., 2015).

Figure 1.3

Strategies for Habit Disruption Aligned with the Psychological Processes of Habitual Behavior



Note. After Gardner et al. (2021, p. 3)

When participants dis-continued their old commuting habits due to relocation of the workplace (i.e., habit disruption), habit strength of the old commuting behavior was demonstrated to decrease linearly, while habit strength of the new commuting behavior grew. At the end of the study period after four weeks, the old commuting habit strength had weakened but had not disappeared. It remained unknown however, how habit strengths might have developed beyond the study period of four weeks (Walker et al., 2015).

Gardner et al. (2021) proposed that habit discontinuation and habit inhibition primarily disrupt habitual behavior, whereas habit substitution potentially changes underlying context-response associations of old habits (Gardner et al., 2021). When repeatedly showing an alternative behavior in an old habit context, a new context-response link forms and eventually becomes relatively stronger than the old habit association. The new habitual behavior should then be initiated more efficiently and should be carried out more likely compared to the old behavior (Lally & Gardner, 2013). For example, someone who habitually reached for a sugary snack (i.e., habitual response) when coming home from work (i.e., context) might develop a new habit where arriving home prompts them to take a short walk or drink water instead.

Trajectories of Habit Decay

Currently, not much is known about change trajectories of old, unwanted habits when a habitual response is being substituted with a new alternative. Whereas some researchers assume that mental representations of context-response associations persist (Adriaanse et al., 2011; Bouton, 2000), others propose that the strength of an old habit diminishes when an old habitual behavior is replaced (Machado, 1997, Lally et al., 2011).

Determinants of Habit Decay

Prior computational studies offered first insights into determinants of habit decay when habit substitution was simulated (Mercuur, 2021; Tobias, 2009).

Repetition of Alternative Behaviors. In the context of waste separation and recycling, old habit strength entirely faded in case the new, intended behavior was enacted consistently in the old context (Tobias, 2009). In the context of simulating the substitution of commuting habits, habit strength decayed when only one single alternative behavior was performed (e.g., instead of taking the car always biking to work) but persisted if different alternative responses were enacted (e.g., instead of taking the car, sometimes biking, sometimes taking the bus; Mercuur et al., 2021). The latter scenario might more closely resemble real-life situations in which individuals may alternate different commuting behaviors due to changing weather or health conditions. As of yet, longer-term, real-life assessments of change in old habit strength when individuals attempt to substitute a habit are still scarce (Gardner et al., 2021).

Experienced Regret. Beyond consistency and type of the alternative response, affective experiences associated with the old habitual behavior may be linked to habit decay. Just like experienced reward is assumed to strengthen context-response links in habit formation, experienced regret of the old behavior could weaken existing context-response links (Skinner, 1938; Wood & Rünger, 2016). Learning experiments have shown that aversive consequences facilitate behavioral extinction (Bouton et al., 2021). Negative emotional reactions to unintended habitual actions can further prompt reflective processing of that behavior (Lee, 2016), potentially impacting the context-response associations (Wood & Neal, 2007).

The Within-Person Versus Between-Person Level in Habit Research

One impediment in habit research is the predominance of studies conducted at the between-person level, examining links that apply to the aggregate of the sample drawn (i.e., person average levels across all measurement time points). However, change in habit strength is assumed to be a highly individual process and should therefore be modeled as a function of both within-person and between-person variance of predictor variables (Kwasnicka et al., 2018).

The between-person level reflects a trait-like, time-invariant component, while the within-person level reflects a state-like, time-varying component that describes fluctuations around one's person mean over time. Importantly, theoretical frameworks on change in habit strength, such as the framework of habit formation (Gardner & Lally, 2018), make predictions at the within-person but not between-person level. For instance, it is hypothesized that an increase in experienced reward should lead to higher habit strength within persons over time, rather than assuming that individuals who report higher average reward also report higher average habit strength than those individuals who report lower average reward (Gardner & Lally, 2018; Gardner et al., 2021). Moreover, associations observed at the between-person level do not necessarily translate to the within-person level (Hamaker, 2012)

Despite the importance of modeling determinants of change in habit strength at the within-person level, only a limited number of studies have adopted this approach (e.g., Kilb & Labudeck; Weyland et al., 2020). One promising methodology for capturing within-person and between-person processes is Ecological Momentary Assessment (EMA), which involves repeated, real-time assessments. Ecological Momentary Assessment (EMA) studies are, for instance, a feasible approach to examine within-person and between-person processes in behavior and habit change as these study designs involve repeated assessments, allowing for the examination of within-person changes in variables of interest over time (Shiffman et al., 2020).

Summary of the Aims and Research Questions of This Dissertation

This thesis examined the role of habit in real life health behavior change and its determinants. More specifically, the following research questions were addressed:

RQ 1: How do Reflective Processes (i.e., Intention Strength and Spontaneous Action Planning) and Habit Interact When Guiding Complex Health Behavior?

Forming healthy habits is a promising strategy to maintain initial improvements despite the absence of active intervention ingredients (Lally & Gardner, 2013; McEwan et al., 2020). Accordingly, when habit and intention are aligned, the habit-intention interaction hypothesis proposes that when habit strength is high, intention-behavior links should be diminished (de Bruijn & Rhodes, 2011). Thus, strong habits are assumed to compensate for lowered intention when guiding health behavior (de Bruijn & Rhodes, 2011). As outlined above, evidence regarding the habit-intention interaction hypothesis is inconclusive, which might be due to methodological shortcomings of the prior studies (Gardner et al., 2020). That is, studies might not have captured intention strength that was active at the time of behavioral performance (Gardner et al., 2020). Additionally, to understand the role of habit in complex health behaviors, assumptions of the habit-intention interaction hypothesis should be tested just as well for volitional processes, such as spontaneous action planning. Therefore, *Study 1* examined moderating effects of higher average habit strength on links of within-person intention and within-person action planning with physical activity over a one-year period.

RQ 2: How Do Habits Form Over Time and What Factors Facilitate Habit Formation in Real-Life Settings?

Previous intensive longitudinal studies have examined habit change trajectories, generally revealing similar patterns of faster growth of habit strength in earlier phases of the habit formation process whereas the increase is less pronounced in later phases (e.g., Lally et al., 2010). However, research on habit change trajectories within the context of habit substitution in real-life setting is scarce. In line with theoretical assumptions that habits form faster when behavior is rewarding, prior evidence demonstrated that participants who reported higher intrinsic reward of a healthy nutrition behavior also reported higher habit strength of that behavior (e.g., Wiedemann et al., 2014). However, these findings could not be replicated at the within-person level (e.g., Weyland et al., 2020) and require replication using event-based measures of experienced reward. As reviewed above, also reflective processes, such as anticipated regret and self-efficacy, could strengthen context-response links upon behavioral repetition (Strack & Deutsch, 2004).

Therefore, *Study 2* and *Study 3* examined habit change trajectories as well as cognitive and affect-related factors as proximal drivers of habit formation within individuals.

RQ 3: How Do Habits Decay Over Time and What Factors Facilitate Habit Decay in Real-Life Settings?

When old context-response associations of unwanted habits persist, individuals are at a higher risk to relapse into old habitual behavior (Gardner et al., 2021). Whereas some researchers posit that old habit associations cannot be truly unlearned (Adriaanse et al., 2011; Bouton, 2000), others expect habit strength to decay if the old habitual response is dis-continued or replaced (Lally et al., 2010; Machado, 1997). Evidence from computation simulation studies suggest that old habits decay, when the new behavior is consistently performed in the old context (Tobias, 2009). As a counterpart of reward that is assumed to facilitate habit formation, aversive experiences, like experienced regret when performing the unwanted behavior, could facilitate habit decay (Bouton, 2021). Long-term assessments of habit decay trajectories and their determinants in real-life settings are limited (Gardner et al., 2021).

Therefore, *Study 3* examined trajectories of habit decay and its determinants in the context of habit substitution. Moreover, theoretical determinants of habit decay, i.e., context-dependent repetition of the new behavior and experienced regret of the old behavior were examined.

Study Projects Used in This Thesis

The first research question on how reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding health behavior was examined based on the empirical findings of *Study 1*. The second research question on how habits form over time and what factors facilitate habit formation in real-life settings was addressed using empirical findings from *Study 2* and *Study 3.* The third research question on how habits decay over time and what factors facilitate habit decay in real-life settings was examined using empirical finding of *Study 3*. In the following sections Study 1-3 are briefly described.

Study 1 is a secondary analysis from a pre-registered randomized controlled trial ("Days in Motion (DiM)", Knoll et al., 2017), designed to examine effects of a dyadic planning intervention on physical activity in 346 healthy, heterosexual, and cohabiting couples living in Berlin metropolitan area (Knoll et al., 2017; ClinicalTrials.gov; NCT01963494). For detailed eligibility criteria, recruitment strategies, intervention procedures, and randomization procedures see: Keller et al., (2020) and Knoll et al. (2017).

Participants provided informed consent at baseline. During the intervention session one week later, participants were randomly assigned to their study role (i.e., target or partner) and to one of the three study conditions: a dyadic planning condition, an individual planning condition, and a control group (see Keller et al. (2020) for the intervention material).

For the present thesis, data of those couple members were analysed who were assigned to the study role of a target person of the two planning intervention arms of the trial (n = 111 from the dyadic planning condition and n = 114 from the individual planning condition; in total n = 225). Subsequent to baseline assessment, participants provided data at one-week, 6-week, 19-week, 26-week, and a 52-week follow-up. Intention strength, spontaneous action planning, and physical activity levels were assessed at all measurement points spanning one year. This provided data to examine differential links of within-person fluctuations of intention and action planning with physical activity levels at different levels of between-person habit strength.

Study 2 is a secondary analysis of an online-based intensive longitudinal randomized controlled trial ("Habit Study", Keller et al., 2021); https://www.drks.de; DRKS00016720), designed to examine effects of self-selected action plans on habit formation that were based on a routine versus time cue in 192 healthy adults living in Berlin, Germany (Keller et al., 2021; https://www.drks.de; DRKS00016720). Detailed recruitment strategies, eligibility criteria, intervention procedure, and randomization procedure are reported by Keller et al. (2021).

During the initial baseline session (Day = 'D'; D0), participants provided informed consent, completed baseline questionnaires and were randomly assigned to one of the planning intervention conditions (i.e., routine-based cue condition, or time-based cue condition). In both conditions participants received general information about healthy nutrition behaviors and were subsequently advised to form a context-behavior plan for one self-selected healthy nutrition behavior that was not yet performed regularly. Participants in the routine-based context condition were instructed to pick a context that was based on a daily routine (e.g., after dinner), whereas participants in the time-based context condition were asked to include a time cue (e.g., at 7 pm). At the end of the session, participants were asked to enact their new behavior in the planned context every day and fill in questionnaires every evening for the subsequent 12 weeks (i.e., 84 days; D1-D84). The study was approved by the first author's institution granted ethics approval for this study.

Of the enrolled sample of *n* = 192 adults (86.5% female), *n* = 135 (routine condition: *n* = 65; time condition: *n* = 70) provided data beyond D60 and for at least 6 days and thus were retained for data analyses (Lally et al., 2010; Laurenceau, 2013). *Study 2* analyzed data from daily questionnaires that were sent to participants every evening for across 12 weeks (i.e., 84 days) that assessed habit strength of the healthy nutrition behavior, intrinsic reward, anticipated regret, and self-efficacy. *Study 2* was therefore particularly feasible to examine within-person associations of theoretical determinants of habit formation.

Study 3 is a primary analysis of an online planning one-arm pre-post intervention study ("Healthy, Active, and Sustainable Commuting Intervention Study", HASCI), DRKS00028479, https://drks.de/register/de/trial). Data of *n* = 42 participants were analyzed. After baseline week, participants created an action plan for a new, more active commuting behavior in an online planning intervention, followed by five post-intervention measurement weeks spanning 14 weeks. The participants were instructed to perform their new commuting behavior for the rest of the study period. During the measurement weeks participants provided multiple-a-day workday assessments, that included reports of their experienced reward and regret of the commuting behaviors, whether they performed their new commuting behavior as planned, and their habit strength of the old and new commuting behavior. Data of *Study 3* allowed to examine both, change in habit strength of the old as well as new commuting behavior and theoretical determinants of that change at the within-person level.

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Chapter 2: Habits and Self-Efficacy Moderate the Effects of Intentions and Planning on Physical Activity (Study 1)

Di Maio, S., Keller, J., Hohl, D. H., Schwarzer, R., & Knoll, N. (2021). Habits and self-efficacy moderate the effects of intentions and planning on physical activity. *British Journal of Health Psychology*, *26*(1), 50 – 66. https://doi.org/10.1111/bjhp.12452

Abstract

Objectives: Behavioral intentions as well as action planning can facilitate the adoption and maintenance of physical activity under certain conditions. The present study examined levels of plan-specific self-efficacy and habit strength as possible conditions that may modify this relationship.

Design: As a secondary analysis of a larger randomized trial to improve physical activity, *n* = 225 recipients of a planning intervention were followed up at five measurement points over one-year. Methods: Two-level models were fit. Within-person levels, i.e., fluctuations of intention and action planning around person means were modelled to predict self-reported moderate-to-vigorous physical activity. Moreover, between-person, i.e., average person-levels of self-efficacy and habit strength were specified as putative moderators of this relationship.

Results: The within-person intention-activity relationship was moderated by between-person levels of habit strength, yielding a compensatory effect: higher than usual intention predicted physical activity only when average activity habit levels were low. The within-person planning-activity relationship was moderated by between-person levels of self-efficacy, yielding a synergistic effect: higher than usual planning combined with high average self-efficacy resulted in highest physical activity levels.

Conclusion: Higher than usual intention may only be required in the presence of low activity habits. Moreover, high self-efficacy seems to be required to translate higher than usual action planning into augmented physical activity because self-efficacious individuals may invest more efforts to enact their plans.

Keywords: Physical activity, intentions, action planning, self-efficacy, habit strength

Physical activity has been found to have a beneficial impact on health and well-being for virtually everyone (Rhodes et al., 2017). The pressing need for behavioral change has led to a persistent research effort focused on psychological determinants of physical activity. Health behavior theories posit the behavioral intention - the motivation to engage in physical activity - to be a proximal antecedent of behavior change (Conner & Norman, 2015). However, meta-analyses have found only weak relationships between experimentally manipulated intentions and increased engagement in physical activity (Rhodes, & Dickau, 2012). This disconnect, the so-called intention-behavior gap, describes on the one hand non-intenders who are subsequently active and on the other hand intenders who do not enact their desired target behavior. For the latter group (i.e., inclined abstainers) a widely recognized technique to bridge the intention-behavior gap is to form an action plan (Orbell & Sheeran, 1998; Webb & Sheeran, 2006). While forming action plans, individuals mentally link situational cues (e.g., “where”, “when”) to a behavioral response (i.e., “how to become active”; Gollwitzer, 1999). Nevertheless, null-effects and considerable heterogeneity of effect sizes across planning intervention studies show that action planning alone is no panacea for improvements in physical activity (Bélanger-Gravel et al., 2013). The failure of intentions and planning to fully account for subsequent behavior change indicates that other psychological factors might moderate this relationship. Such moderating effects may explain: a) conditions under which individuals engage in physical activity despite their low intentions or lack of action planning, and b) conditions under which good intentions or planning are effective. Possible candidates for such psychological moderators could be habit strength and self-efficacy.

Habit Strength as a Moderator

So far, health behavior theories have largely focused on the role of reflective processes in predicting physical activity (Fishbein & Ajzen, 2010). However, habits, defined as learned processes by which a cue generates an impulse to act, are characterized by a high degree of automaticity and efficiency (Lally et al., 2010). Thus, habits are expected to produce behavior in response to cues more rapidly and effectively than do reflective processes. Accordingly, studies examining if habit strength moderated the influence of reflective processes (i.e., intentions, planning) on physical activity suggest that high habit strength of physical activity may side-step motivational or volitional deficits or make them obsolete (de Bruijn & Rhodes, 2011; Gardner et al., 2011; Maher & Conroy, 2015; Rebar et al., 2014; van Bree et al., 2013). Eight of nine systematically reviewed studies (Gardner et al., 2011) and further studies beyond those covered in the review (de Bruijn & Rhodes, 2011; van Bree et al., 2013) reported that intention was linked to behavior only among participants with low and medium levels of habit strength, whereas among participants with strong habits, intention was not linked to health behavior. Moreover, a daily diary study conducted by Rebar et al. (2014) found that persons' average habits were unrelated to physical activity unless their daily intentions were weaker than usual, suggesting a compensatory effect of behavioral intentions and habits when predicting physical activity (Rebar et al., 2014).

Although research on the role of planning in habit formation suggests that planning and habit act in partial concert (Gardner et al., 2014) thus far the moderating effect of habit on the planning-behavior link has received relatively little attention (Maher & Conroy, 2015). Action plans are assumed to tie situational cues with behavioral responses (Gollwitzer, 1999)**.** Upon frequent repetition, individuals are assumed to internalize these cue-behavior associations and behavioral control is assumed to shift to situational cues that become sufficient to prompt an automatic response (Gardner et al., 2011). One study examining the moderating role of habit strength for the action planning-physical activity relationship found that participants with strong habits did not benefit from action planning (Maher & Conroy, 2015). In contrast, action planning was beneficial when participants reported weak physical activity habits (Maher & Conroy, 2015). Yet, further research is needed to clarify whether planning becomes superfluous when strong automatic processes take over or whether planning and habit formation are ongoing processes, respectively contributing to behavioral changes.

In the current study, participants formed action plans including individualized information about each activity's contextual cue. Thus, physical activity habits explicitly referred to behavior within the context outlined by the plans allowing to disentangle mere behavioral repetition performed across contexts from habitual behavior elicited by contextual cues (Sniehotta & Presseau, 2012).

Self-Efficacy as a Moderator

Individuals are not only reactive organisms, but proactive ones, anticipating what it will take to fulfill the self-set standards and in turn mobilize their effort and personal resources. Perceived self-efficacy reflects individuals' beliefs in their capabilities to exercise control over a particular task and over their own functioning, and it represents optimistic beliefs about one's capability to cope with barriers that arise during the period of behavioral maintenance (Bandura, 1997). Thus, individuals' self-examination of their own functioning is assumed to predict whether individuals adopt physical activity from positive initial intentions (Bandura, 1997). Accordingly, research investigating the role of self-efficacy in individuals who intended to engage in physical activity found that levels of self-efficacy distinguished between unsuccessful and successful intender profiles (Rhodes et al., 2008). That is, self-efficacious individuals were more likely to successfully translate their good intentions into action than individuals low in self-efficacy (Rhodes et al., 2008).

As reviewed above, ample prior research has found support for planning mediating the intention-behavior relationship (Webb & Sheeran, 2006). However, conditions for performing physical activity might be unfavorable, such as bad weather or physical discomfort, preventing the person from actually executing the plan. In such situations, self-efficacy is required to overcome obstacles that might derail the intended action, to overcome setbacks and recover from failed attempts to enact the target behavior, and to stimulate self-motivation repeatedly. Correspondingly, self-efficacy was found to operate as a moderator explaining the relationship between planning and physical activity (Lippke et al., 2009; Luszczynska et al., 2011). There is evidence that self-efficacious individuals were more likely to translate their plans into behavior than individuals who had low levels of self-efficacy (Lippke et al., 2009; Luszczynska et al., 2011). Findings support this moderation by self-efficacy for both spontaneous (Lippke et al., 2009) and experimentally induced action planning (Luszczynska et al., 2011).

In the current study, self-efficacy is assessed at a very specific, individual level (i.e., individuals' self-selected plans) to account for the idiothetic and specific nature of the self-efficacy construct (Scholz et al., 2005). That is, items to assess self-efficacy precisely reflect the conditions of the specific activity (Scholz et al., 2005).

Between-Person vs. Within-Person Processes of Behavior Change

Socio-cognitive variables are assumed to contain a relatively stable trait-like component (i.e., between-person) and likewise, a state-like, time-varying component (i.e., within-person). The between-person component reflects differences in study variables between individuals (i.e., person average level across all measurement time points). The within-person component, on the other hand, indicates individuals' variation around their own mean level of a measure (i.e., higher/lower than usual; Inauen et al., 2016). Most studies have examined associations among the above reviewed relationships focusing on between-person differences, however, associations such as the intention-behavior relationship can and should also be conceptualized as within-person processes (Inauen et al., 2016). Prior research has demonstrated that patterns of associations involving intentions, action planning, and physical activity at the between-person level did not necessarily translate to the within-person level (Bierbauer et al., 2017). Accordingly, Rebar et al. (2014) found that whereas person average levels of intention did not moderate the link between average person habit strength and physical activity, within-person fluctuations of intention (i.e., higher or lower intentions than usual) moderated the habit-behavior link (Rebar et al., 2014). In the present study, within-person levels, i.e., fluctuations of intention strength and action planning around person means were modelled to predict physical activity levels.

Aims and Hypotheses

The present study aims to examine the relationships of intention strength and action planning with moderate-to-vigorous physical activity (MVPA). It is examined whether within-person fluctuations, i.e., higher or lower than usual levels of intention strength or action planning are linked to MVPA, as a function of between-person, i.e., person average levels across all measurement time points of habit strength or self-efficacy. Based on behavior change theories (e.g., Fishbein & Ajzen,

2010) and habit formation literature (e.g., Gardner et al., 2011), participants high in between-person habit strength ('H'=Hypothesis; H1a), or self-efficacy (H1b) are expected to report higher MVPA than those with low between-person habit strength, or self-efficacy (i.e., main effects of moderators). Moreover, we propose that higher within-person intention strength (H2a), and action planning (H2b) would yield higher MVPA (i.e., main effects of predictors). In addition, we expect the link between within-person intention strength or action planning with MVPA to vary at different levels of between-person habit strength or self-efficacy (i.e., cross-level interactions). That is, we expect that the relationship of within-person intention strength (H3a) and planning (H3b) with MVPA should be attenuated for participants with high between-person habit strength compared to those with low between-person habit strength. Moreover, the relationship of within-person intention strength (H4a) and planning (H4b) with MVPA should be more pronounced in individuals with higher between-person self-efficacy than for those with lower between-person self-efficacy.

Methods

Procedure and Participants

This study is a secondary analysis from a pre-registered randomized controlled trial (RCT), designed to examine effects of a dyadic planning intervention on physical activity in 346 healthy, heterosexual, and cohabiting couples living in Berlin (Knoll et al. 2017; ClinicalTrials.gov; NCT01963494). Detailed eligibility criteria, recruitment strategies, intervention procedures, and randomization procedures were reported elsewhere (Keller et al., 2020; Knoll et al., 2017). Participants provided informed consent at baseline. During the intervention session (one week later), participants were randomly assigned to their study role (i.e., target person or partner) and to one of the three study conditions: a dyadic planning condition, an individual planning condition, and a control group. For the current study, data of n = 225 couple members were analyzed who were assigned to the study role of a target person of the two planning-intervention arms of the trial (n = 111 from the dyadic planning condition and n = 114 from the individual planning condition). Data from target persons of the control condition, who did not form action plans, were not included. In the dyadic planning condition, target persons jointly formed and discussed their plans with their partner. In the individual planning condition, target persons formed their plans alone, while their partner worked on a stone sculpture interpretation task in a separate room. Target persons were instructed to form up to five action plans to increase daily physical activity in a 'when'-'where'-'how' format, followed up by reframing this information in an "If/When, then" format (e.g., "When I come home from work, then I will take a brisk 20-min walk in the park."). Subsequently, five assessments were a one-week, 6-weeks, 19-weeks, 26-weeks, and a 52-weeks follow-up. The study was approved by the last author's Institutional Review Board.

Of the examined sample of *n* = 225 participants (women: *n* = 112, 49.8%), *n* = 181 provided data at the 52-weeks follow-up (80.44%). Participants' mean age was 38.37 years (*SD* = 15.14, range: 19 to 78 years). Most participants (*n* = 171, 76%) reported having a high school diploma, about half reported having a university degree (*n* = 97, 43.1%). The majority (n = 157, 69,8%) reported to be currently employed and *n* = 23 (10.2%) were retired.

Measures

Unless otherwise noted, data were collected at the five post-intervention sessions, and response formats were six-point Likert scales ranging from "*does not apply at all*" (1) to "*applies exactly*" (6). Item examples provided below are translated from German.

Moderate-to-Vigorous Physical Activity (MVPA)

Across all follow-up assessments, self-reported physical activity was measured with the Office in Motion Questionnaire (OIMQ; Mader et al., 2006) which was extended by items measuring housekeeping and work from the extended version of the Physical Frequency Questionnaire (PAFQ; Bernstein et al., 1998). The questionnaire consisted of a list of 55 common physical activities (e.g., "fast or uphill walking", "cooking, doing the dishes", or "basketball") with the option to include up to three additional activities. Participants indicated the number of days (0-7) and the duration (per day) they performed each activity on average over the past 7 days. Data on 38 different physical activities with metabolic equivalent of task (MET) levels of at least 3.0 were used to calculate the MVPA indicator (MET is an objective measure of the ratio of the rate at which a person expends energy;

Jette, Sidney, & Blumchen, 1990). In case the total amount of hours reported (i.e., hours of sleep-time plus hours spent in wake-time activities) did not sum up to 24 hours per day, a two-step adjustment was made (Bernstein et al., 1998). First, if the weekly sleep time exceeded 70 hours (i.e., >10 hours per day) or was below 45.50 hours (i.e., <6.5 hours per day), it was truncated to 70 hours or 45.50 hours, respectively. Second, an *adjustment variable* was computed representing proportional underestimation or overestimation of time spent in physical activity in relation to weekly sleep-time and the week's full 168 hours (7 x 24 hours). Subsequently, the participant-reported duration for each physical activity was adjusted by multiplying the participant reports with the adjustment variable. This procedure resulted in a total of 168 week hours (7 x 24 hours) for each participant, when summarizing (adjusted) hours of sleep-time and (adjusted) hours spent in wake-time activities. To derive daily minutes of MVPA across the past 7 days, data of the number of days and duration per day were multiplied for each physical activity, summarized across all 38 physical activities, and divided by 7. Univariate outliers were adjusted by winsorizing daily MVPA levels of $z > |3.29|$ to one unit lower or higher than the next lowest or highest value in the distribution (Tabachnick & Fidell, 2007).

Intention Strength (Henceforth Intention)

Intention strength (i.e., the intensity of participants' commitment to act on their intentions, Rhodes & Rebar, 2017) was assessed using a scale adapted from Sniehotta et al. (2005). Participants responded to three general intentional statements: a) "I intend to be more physically active during my leisure time (e.g., swimming, walking). ", b) "I intend to be more physically active during everyday life (e.g., taking the stairs, housework, or gardening), c) "I intend to travel more frequently on foot or by bicycle.". Cronbach's alpha ranged from .66 to .85.

Action Planning (Henceforth Planning)

Action planning was assessed with four items using the stem "During the past 7 days, I have made detailed plans…", followed by (a) "when," (b) "where," (c) "how," (d) "how often to be physically active" (Sniehotta et al., 2005). Cronbach's alpha ranged from .95 to .96.

Plan-Specific Self-Efficacy (Henceforth Self-efficacy)

At the intervention session, self-efficacy was assessed for each of the five plans. Participants responded on a 4-point scale [ranging from “not true” (1) to “exactly true” (4)] to the statement “I am confident that I will be able to perform my behavior in the situation exactly as planned” (Scholz et al., 2005). Cronbach’s alpha was .43.

Plan-specific Habit Strength (Henceforth Habit Strength)

At all follow-up assessments and specific to participants’ self-selected plans (i.e., their activity in combination with the contextual cue), habit strength was assessed using the previously validated self-reported behavioral automaticity index (SRBAI), a subscale of the Self-Report of Habit Index (SRHI, Gardner et al., 2012; Verplanken & Orbell, 2003). The item stem “Being as physically active, *as I have planned it,* is something...” was followed by four statements concerning automaticity (e.g., “I do automatically or “I do without thinking.”). Cronbach’s alpha ranged from .91 to .94.

Covariates

The following covariates assessed at baseline were included: gender (0 = women, 1 = men), age, and objectively measured body-mass-index (BMI). Also, a dummy-coded planning condition variable (0 = individual planning condition; 1 = dyadic planning condition) was used as a covariate.

Full measures of psychological variables and five (out of 38) exemplary items for MVPA measure are provided in Appendix A.

Analyses

Using IBM SPSS 25, descriptive statistics and intraclass correlations (ICC) of study variables and their bivariate correlations were computed. We estimated two-level models with repeated assessments nested in individuals using Mplus 7 (Muthén, 1998-2012). Repeated assessments of predictor variables (i.e., intention and planning) and habit strength were grand-mean centered and then person-mean centered, creating between- and within-person components (Bryk, 2002). The between-person component describes the deviation of a participant’s average score from the grand mean (average score across all participants). The within-person component reflects each participants’ deviation from their own person mean (i.e., a participant’s average score across all assessments). Four separate ‘*intercept and slope as outcomes*’ two-level models with MVPA as the outcome were fit (Luke, 2004). Models 1a (within-person intention as predictor) and 1b (within-person planning as predictor) included between-person habit strength as the moderator and Models 2a (within-person intention as predictor) and 2b (within-person planning as predictor) included between-person self-efficacy as the moderator. To test for cross-level moderator effects, the random slopes of the within-person predictors (within-person intention or planning) were specified as a function of the between-person predictors (between-person self-efficacy or habit strength). All models were controlled for between-person indicators of the respective predictor (intention or planning), time-dependent variation in MVPA by adding a random linear time slope (coded in weeks following the intervention) to each model, and covariates. A full information maximum likelihood procedure was applied to keep all available data in the analyses.

Simple slopes for moderators were plotted at their mean and at one standard deviation below and above their mean. This was followed up by simple slope analyses using the Johnson-Neyman technique to examine regions of significance of the simple slopes (Preacher, 2006).

Results

Descriptive Results

Table 2.1 displays descriptive statistics and ICCs among study variables. Across follow-up assessments, participants reported to spend a mean of 95.24 (*SD* = 78.45) minutes in MVPA per day. The ICC for MVPA was 0.46 indicating that less than half of the total variance in overall MVPA was explained by between-person differences, whereas the majority of the variance was due to within-person differences and measurement error.

Table 2.1

Means, Standard Deviations, and Intraclass Correlations

Variables	*Range*	*M_B (SD_B)*	*SD_W*	*ICC*
1 Daily MVPA	0-355.87	95.24 (78.45)	51.08	.46
2 Habit Strength (1-6)	1-6	2.67 (1.07)	0.74	.58
3 Intentions (1-6)	1-6	4.28 (1.18)	0.68	.57
4 Planning (1-6)	1-6	3.49 (1.59)	1.17	.31
5 Self-Efficacy (1-4)	1-4	3.05 (0.35)		
6 BMI	18.11 - 45.11	25.59 (4.57)		
7 Age	19 - 78	38.37 (15.14)		

Note. M_B: Mean at the between-person level. SD_B: Standard deviation at the between-person level. SD_W: Standard deviation at the within-person level. *ICC*: Intraclass correlation.

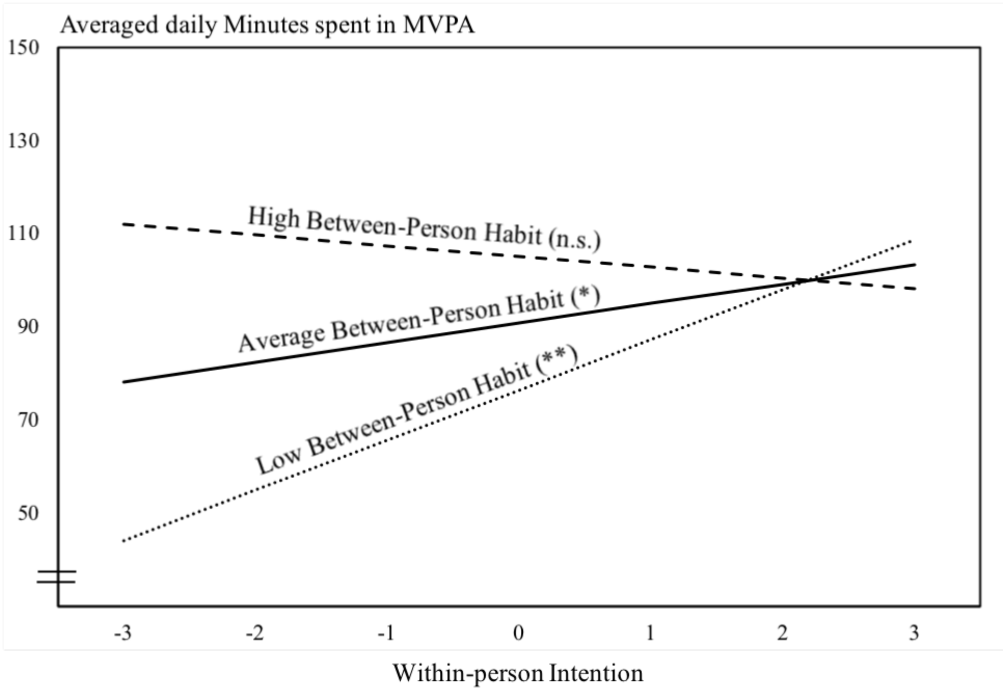
Associations and Interactions of Within- and Between-Person Predictors With MVPA

Models testing hypotheses are displayed in Tables 2.2 and 2.3. In accordance with H1a and H1b, significant associations of between-person habit strength and between-person self-efficacy with MVPA were found. Participants who reported high average levels of habit strength or self-efficacy were likely to spend more minutes in MVPA. Not in line with H2a, within-person intention was not linked with MVPA. In accordance with H2b, within-person planning was positively linked with MVPA. That is, participants who planned more than usual also spent more minutes in MVPA.

In line with H3a, the association between within-person intention and daily MVPA significantly varied as a function of different levels of between-person habit strength. Simple slope analyses (see Figure 2.1) illustrated that higher than usual intention was related to more MVPA in participants with low average habit strength (*b (SE)* = 10.75 (2.40), $p < .001$) and medium average habit strength (*b (SE)* = 4.21 (1.72), $p = .026$).

Figure 2.1

Within-Person Intention – Physical Activity Link as a Function of Between-Person Habit Strength



Note. Relationship between fluctuations of within-person intention and minutes spent in moderate-to-vigorous physical activity (MVPA) for low (*M*-1*SD* = -1.06), average and high levels (*M*+1*SD* = 1.06) of between-person habit strength. *Note*. n.s.: non-significant. *p<.05, **p <.01.

In participants with high average habit strength, reporting higher than usual intentions was unrelated to MVPA (*b (SE)* = 2.33 (2.42), *p* = .349). Post-hoc analyses on regions of significance using the Johnson- Neyman technique indicated that within-person intention-mvpa relationships were significant given centered between-person habit strength levels were below 0.09. Not in accordance with H3b, the relationship between within-person planning and MVPA was not moderated by habit strength (see Table 2.2).

Table 2.2

Effects of Two-level Models Testing the Relationship Between Intention (Model 1a) and Planning (Model 1b) With MVPA, Moderated by Habit Strength

	Outcome: Daily MVPA			
	Model 1a		Model 1b	
	b (*SE*)	*p*	*b* (*SE*)	*p*
Fixed Effects				
Intercept	90.80 (7.37)	<.001	89.89 (7.32)	<.001
Time	-0.06 (0.12)	.613	-0.05 (0.11)	.691
Intention (within)	4.21 (2.94)	.153		
Planning (within)			5.45 (1.59)	.001
Intention (between)	-1.13 (4.28)	.790		
Planning (between)			1.01 (3.83)	.776
Habit Strength (between)	13.51 (3.69)	<.001	13.71 (3.75)	<.001
Intention (within) x Habit Strength (between)	-6.17 (2.55)	.015		
Planning (within) x Habit Strength (between)			0.93 (1.41)	.510
Random Effects	Var (*SE*)		Var (*SE*)	
Intercept	3131.55 (444.27)	<.001	3048.51 (444.08)	<.001
Time	0.63 (0.30)	.033	.46 (.28)	.098
Intention (within)	184.48 (145.64)	.205		
Planning (within)			19.56 (39.72)	<.001
Residual	2946.54 (186.76)	<.001	3042.58 (187.99)	<.001

Note. Models controlled for gender, age, body-mass-index, intervention group, time, and between-person components of intention, or planning.

Also not in line with H4a, the relationship between within-person intentions and MVPA was not further moderated by between-person self-efficacy, as indicated by a non-significant intention x self-efficacy interaction (see Table 2.3).

Table 2.3

Effects of Two-level Models Testing the Relationship Between Intention (Model 2a) and Planning (Model 2b) With MVPA, Moderated by Self-Efficacy.

	Outcome: Daily MVPA			
	Model 2a		Model 2b	
	b (*SE*)	*p*	*b* (*SE*)	*p*
Fixed Effects				
Intercept	92.57 (7.47)	<.001	90.08 (7.44)	<.001
Time	-0.08 (0.12)	.483	-0.04 (0.11)	.707
Intention (within)	4.51 (3.00)	.132		
Planning (within)			5.47 (1.53)	<.001
Intention (between)	-2.72 (4.39)	.535		
Planning (between)			2.00 (3.89)	.607
Self-Efficacy (between)	26.25 (11.01)	.017	25.23 (6.19)	<.001
Intention (within) x Self-Efficacy (between)	-1.52 (8.03)	.850		
Planning (within) x Self-Efficacy (between)			11.03 (0.06)	<.001
Random Effects	Var (*SE*)		Var (*SE*)	
Intercept	3194.98 (451.05)	<.001	3148.87 (3.78)	<.001
Time	0.56 (.30)	.059	0.38 (0.13)	.005
Intention (within)	217.17 (155.05)	.161		
Planning (within)			0.338 (0.04)	<.001
Residual	2997.59 (190.40)	<.001	3099.40 (159.70)	<.001

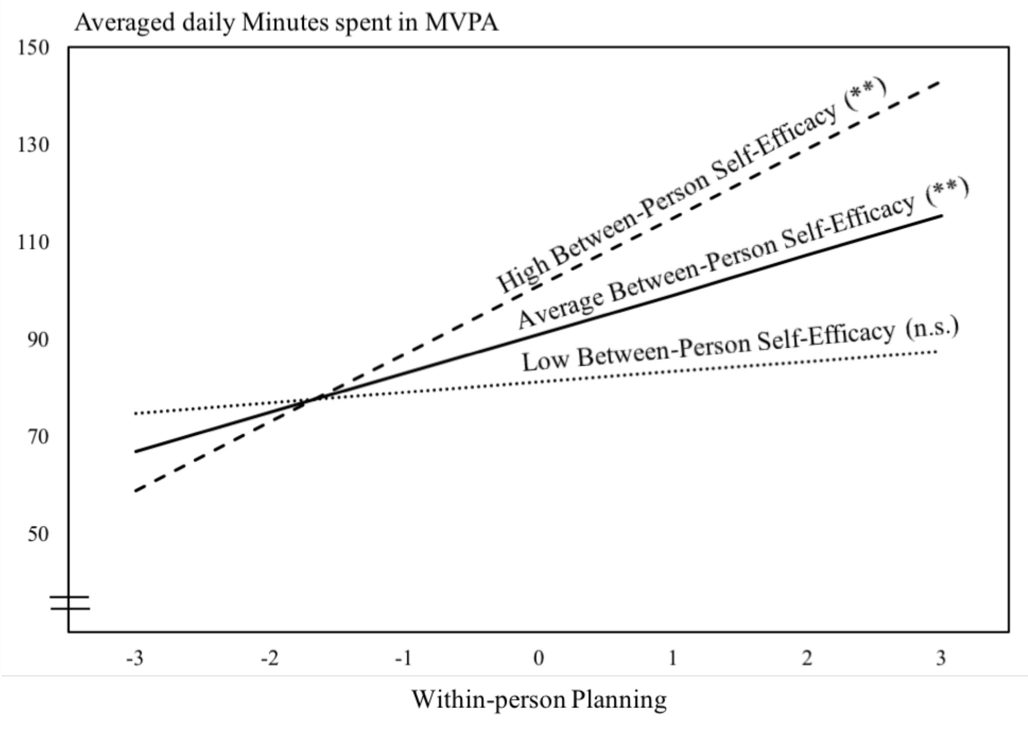
Note. Models controlled for gender, age, body-mass-index, intervention group, time, and between-person components of intention, or planning.

In line with H4b, the association between within-person planning and MVPA differed as a function of between-person self-efficacy, as reflected by a significant planning x self-efficacy interaction (b (SE) = 11.13 (0.06), $p < .001$). Simple slope analyses (see Figure 2.2) showed that planning more than usual was significantly related to more MVPA in participants who reported high (*b (SE)* = 9.35 (1.46), $p < .001$) and medium average levels of self-efficacy (*b (SE)* = 5.39 (1.24), $p < .001$). Within-person planning was unrelated to MVPA for participants who reported low between-person self-efficacy (*b (SE)* = 1.42 (1.46), $p = .344$). Post-hoc analyses on regions of significance using the Johnson-Neyman technique showed that within-person planning-mvpa relationships were significant given centered between-person self-efficacy levels were above -0.24.

Across all models, between-person intention and between-person planning were unrelated to MVPA.

Figure 2.2

Within-Person Action Planning – Physical Activity Link as a Function of Between-Person Self-Efficacy



Note. Relationship between fluctuations of within-person planning and minutes spent in moderate-to-vigorous physical activity (MVPA) for low (M-1SD = -0.37), average, and high (M+1SD = 0.37) levels of between-person self-efficacy. *Note*. n.s.: non-significant. **p <.01

Discussion

Engagement in and maintenance of physical activity requires knowledge about conditions that affect the likelihood of acting on one's own behavioral intentions and plans. This study investigated how within-person intention and within-person planning were linked to MVPA, and whether these links varied as a function of between-person habit strength or between-person self-efficacy. As hypothesized, participants who reported higher average levels of habit strength (H1a), higher average levels of self-efficacy (H1b), or more than usual planning (H2b) were more likely to engage in higher MVPA. Not in line with H2a, participants' higher than usual intention was not linked to more minutes spent in MVPA. However, when participants reported weak or medium average levels of habit strength, higher than usual intention was a significant positive correlate of MVPA whereas for participants with high average levels of habits, intention was unrelated to MVPA (H3a). Unexpectedly, the relationship between within-person planning and MVPA was not further qualified by participants' habit strength (H3b). Not in line with H4a, the within-person intentions and MVPA association was not further moderated by between-person self-efficacy. However, the within-person planning-MVPA relationship was particularly pronounced among participants with medium or high between-person self-efficacy, whereas it was not observed at low levels of between-person self-efficacy (H4b). That is, higher than usual planning combined with high average self-efficacy resulted in highest physical activity levels.

Mirroring the results reported by Bierbauer et al. (2017) we found higher-than-usual intentions not being associated with more physical activity. This corroborates a large body of research that has evidenced the existence of an intention-behavior gap at the between-person level (Rhodes, & Dickau, 2012; Sheeran, 2002; Sheeran & Webb, 2016) leading to the assumption that behavior is - amongst others (e.g., see for overview Sheeran & Webb, 2016) - guided by nonreflective automatic processes (i.e., habit). Accordingly, in line with prior research, we found that only in the absence of strong physical activity habits a close association between intentions and physical activity emerged (de Bruijn & Rhodes, 2011; Gardner et al., 2011; van Bree et al., 2013). Habits may render individuals immune to behavioral consequences of low intentions, whereas intentions can translate into behavior when habits are weak. Where habits and intentions conflict, behavior tends to proceed in line with the habits and not with the intentions (de Bruijn & Rhodes, 2011; Gardner et al., 2011; van Bree et al., 2013). This can be seen as beneficial when strong habits compensate for motivational and volitional deficits in the maintenance or increase of regular physical activity (Gardner et al., 2011). Moreover, increasing intention may be an effective tool for increasing nonhabitual behavior (i.e., varying contexts and activities; Ouellette & Wood, 1998). However, when physical activity levels are low, but strongly habitual, increasing intention may be ineffective for yet necessary behavior change. Indeed, people who have strong physical activity habits may less likely be in need for a motivational intervention targeting their physical activity. Nevertheless, the present findings underpin the promise of targeting intentions in people who have weak physical activity habits.

Participants who planned more than usual also engaged in more physical activity. This supports findings on the beneficial role of planning for behavioral enactment (Carraro & Gaudreau, 2013). In the present study, spontaneous planning following an intervention was an important physical activity correlate, irrespective of a person's plan-specific habit strength, whereas Maher and Conroy (2015) found that the effectiveness of experimentally formed plans in promoting physical activity depended on general physical activity habit strength. In the present study, habit strength did not refer to general physical activity but to behavior outlined in the specific action plans themselves, making an interference less likely. Nevertheless, the present results support the assumption that forming if-then plans would supersede weak habits in controlling behavior (Adriaanse et al., 2011). Likewise, action planning did not become superfluous although automatic processes were strong, suggesting that also people who have strong physical activity habits would nevertheless benefit from action planning intervention to boost their physical activity. Future research should examine more fine-grained dynamics of how planning and habit strength are interrelated and contribute to behavior change (Lally et al., 2010).

Self-efficacious individuals are assumed to expend more effort in goal pursuit and to be more persistent in the face of setbacks or difficulties (Lippke et al., 2009; Luszczynska et al., 2011; Rhodes et al., 2008). Accordingly, in this study participants who reported higher average self-efficacy also engaged in more physical activity. Moreover, the combination of high average self-efficacy and more planning than usual resulted in the highest physical activity levels which can be interpreted as a synergistic effect. The more confidence individuals had in their own abilities, the more they benefitted from planning, whereas participants with low average levels of self-efficacy did not translate their plans into action. This finding supports physical activity intervention approaches that focus on instilling confidence in one's ability to remain active (Keller et al., 2016).

Strengths, Limitations, and Future Directions

The current study has several strengths. First, it adds insights on within-person links between physical activity, intentions, and planning following a planning intervention. The investigation of within-person associations is of particular importance as they can differ from those at the between-person level in size or even direction (Inauen et al., 2016). So far, in research on habits, longitudinal studies spanning one year are scarce. Moreover, very little research has examined the interplay between plan-specific activity habits and the deliberate planning to act on activity intentions. Both, habit strength and self-efficacy are assumed to be best captured when referring to specific situations and individualized activities (Scholz et al., 2005; Sniehotta & Presseau, 2012). Accordingly, we assessed plan-specific habit strength and plan-specific self-efficacy referring to individualized self-selected action plans.

However, some limitations also warrant attention. First, the sample consisted of healthy adults in a longer-term relationship who appeared to be more active than the general population (Keller et al., 2020, Knoll et al., 2017, Pauly et al., 2020). Thus, as results may not generalize to less active adults not living in a relationship, replication is needed to infer more definite conclusions. Second, self-reports assessing physical activity are prone to social desirability, recall bias (Sallis & Saelens, 2000), and overestimation of high-intensity physical activity (i.e., MVPA, Prince et al., 2008; Schaller et al., 2016). Third, we relied on habit self-reports that are assumed to capture habit strength merely as a subjective *experience* of automaticity (e.g., perceived 'fluency' with which the behavior was enacted) and thus may not assess the actual habitual process that is harder to identify retrospectively (Hagger, 2019). Therefore, objective measures of physical activity (i.e., accelerometry) and habit strength (i.e., behavioral repetition) should be favored in future research. Fourth, implied predictive direction remains questionable as within-person associations were based on simultaneous measurement points in time, respectively. Future studies might apply interventional daily diary designs to allow for causal inferences. Fifth, examining the link between planning and physical activity, we cannot conclude whether individuals responded to the cues specified by their action plans. Broad physical activity measures can only serve as a proxy for whether individuals enacted their plans (i.e., plan enactment; Fleig et al., 2017). Future research should measure the degree to which individuals enacted their action plans and how this interacts with self-efficacy and habit strength.

Conclusion

In sum, this study was innovative in its emphasis on the interplay of four psychosocial constructs and their relationships with physical activity. By using multilevel modelling, the study has succeeded in unravelling between-person from within-person components of intentions and planning being related to physical activity under certain conditions of plan-specific between-person self-efficacy and habit strength. This points to possible mechanisms that link higher than usual intention to activity when average habits are weaker and that link more than usual planning to activity when average self-efficacy beliefs are stronger.

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Chapter 3: What helps to form a healthy nutrition habit? Daily associations of intrinsic reward, anticipated regret, and self-efficacy with automaticity (Study 2)

Di Maio, S., Keller, J., Kwasnicka, D., Knoll, N., Sichert, L., Fleig, L. (2022). What helps to form a healthy nutrition habit? Daily associations of intrinsic reward, anticipated regret, and self-efficacy with automaticity. A*ppetite, 175,* Article 106013. https://doi.org/10.1016/j.appet.2022.106083

Abstract

Background. High automaticity in healthy nutrition behaviors is related to long-term maintenance of these behaviors. Drawing upon theoretical frameworks of habit formation, proposed antecedents such as intrinsic reward, anticipated regret, and self-efficacy are important correlates of automaticity, but not much is known about their day-by-day relationships with automaticity in healthy nutrition behaviors. This study tested previous-day within-person (i.e., from one day to the next) and same-day within-person associations of intrinsic reward, anticipated regret, and self-efficacy with automaticity of a healthy nutrition behavior, for which participants attempted to form a new habit.

Methods. Secondary analyses of a randomized controlled trial with two planning intervention conditions including a longitudinal sample of $n = 135$ participants (age: $M = 24.82$ years; $SD = 7.27$) are reported. Participants formed a plan on a self-selected healthy nutrition behavior to become a new habit and were followed up over 12 weeks assessing daily levels of plan-specific intrinsic reward, anticipated regret, self-efficacy, and automaticity. Lagged multilevel models with 84 study days nested in participants estimated previous-day within-person, same-day within-person, and between-person relationships of intrinsic reward, anticipated regret, and self-efficacy with automaticity.

Findings. Regarding within-level relationships, higher-than-usual levels of intrinsic reward, anticipated regret, and self-efficacy of the same day but not of the previous day were associated with higher within-person automaticity. With respect to between-level relationships, higher between-levels (i.e., higher person mean levels across the study period) of intrinsic reward, anticipated regret, and self-efficacy were linked with higher automaticity.

Discussion. Findings point towards the potential to intervene on intrinsic reward, anticipated regret, and self-efficacy when aiming to promote a new healthy nutrition habit.

Keywords: habit formation, automaticity, nutrition, intrinsic reward, anticipated regret, self-efficacy

Chronic conditions such as cardiovascular diseases, diabetes, and cancer remain the leading causes for disability and death worldwide (World Health Organization [WHO], 2019). To prevent chronic conditions, adopting and maintaining health behaviors including healthy nutrition behaviors such as consuming an additional portion of fruit or vegetables a day is crucial (Aune et al., 2017). Although factors that facilitate the adoption of healthy nutrition behaviors are well understood, most individuals fail to sustain initial improvements in the long term (Lemstra et al., 2016). Habit strength (or behavioral automaticity) has been found to be a promising determinant of long-term maintenance of health behaviors (Kwasnicka et al., 2016), such as a healthy diet. 'Habit' has been defined as a process whereby a cue automatically generates an impulse to act that is characterized by a high degree of efficiency (Lally et al., 2008; Wood & Neal, 2007). Therefore, habit strength can be best captured by the degree of behavioral automaticity as it distinguishes habitual behavior (i.e., high automaticity) from frequent intentional behaviors (i.e., low automaticity; Gardner et al., 2012).

Gardner and Lally (2018) proposed that antecedents of behavioral automaticity can be distinguished depending on the stage of behavioral adoption: *stage 1*: motivational antecedents (i.e., variables influencing the decision to act); *stage 2*: volitional antecedents (i.e., variables supporting self-regulation); *stage 3a*: antecedents of behavior maintenance, and *stage 3b*: antecedents that directly influence cue-behavior associations (Gardner et al., 2018). Building upon the habit formation framework by Gardner and Lally (2018), antecedents such as intrinsic reward, anticipated regret (i.e., as a type of outcome expectancies), or self-efficacy can play a role at multiple stages of the habit formation process (stage 1 to stage 3a; Gardner et al., 2018). For instance, the intrinsic reward value of a healthy nutrition behavior (e.g., eating fruits for breakfast) should lead to the context (i.e., breakfast table) signalling both, an opportunity as well as an incentive (i.e., intrinsic reward) for eating fruits and therefore strengthen the intention for the healthy nutrition behavior and prompt its enactment (Wiedemann et al. 2014). In a similar vein, anticipated regret should bind individuals to their intention for healthy nutrition behavior, for example, if not eating fruits for breakfast is expected to prompt negative emotions, such as guilt that are expected to arise due to the regret of inaction and that individuals naturally try to avoid (Sorys & Byrka, 2017). Believing in one's capabilities to make healthy food choices could, for example, be especially beneficial when facing nutrition-related temptations (Anderson et al., 2007). Whether these antecedents also accelerate the cue-behavior learning (stage 3b) is, however, less well understood (Verplanken, 2018).

This is also due to the fact that the vast majority of prior research examined associations of antecedents with automaticity at the between-person level. For instance, positive between-person associations of self-efficacy for a healthy nutrition behavior and automaticity of a healthy nutrition behavior would reflect that people who reported higher person-average levels of self-efficacy, compared to the sample's mean, also reported higher average levels of automaticity. However, the proposed antecedents (i.e., intrinsic reward, anticipated regret, and self-efficacy) were shown to vary intra-individually over time (Bierbauer et al., 2017; Martín et al., 2014). Likewise, systematically gaining automaticity (i.e., habit formation) is a highly individual phenomenon (Lally et al., 2010) that is – by definition – expected to vary over time and should be investigated at the within-person level. For instance, positive within-person associations of self-efficacy for a healthy nutrition behavior and automaticity of a healthy nutrition behavior would reflect that participants who reported higher-than-usual levels of self-efficacy (i.e., higher than their person mean) also reported higher-than-usual levels in automaticity.

To examine processes wherein automaticity fluctuates as a function of varying intra-individual antecedents, research designs that are sensitive to changes of these antecedents and automaticity over short temporal cycles are warranted (Kwasnicka et al., 2018). To include repeated assessments at meaningful intervals that correspond to the purported fluctuation of the antecedents and automaticity of a healthy nutrition behavior, the purpose of the present study was to examine associations between previous-day within-person and same-day within-person intrinsic reward, anticipated regret, and self-efficacy with same-day within-person automaticity levels of a healthy nutrition behavior. Whereas some studies have modelled changes in automaticity at the within-person level (Fournier et al., 2017; Keller et al., 2021; Lally et al., 2010; van der Weiden et al., 2020; Weyland et al., 2020) day-by-day associations between psychological antecedents and automaticity of a healthy nutrition behavior have, to our knowledge, not yet been examined. In the following, we discuss intrinsic reward, anticipated regret, and self-efficacy regarding a healthy nutrition behavior as antecedents that may correlate with automaticity increases on a daily basis.

Intrinsic Reward

Intrinsic reward refers to the experience of a behavior to be inherently rewarding and is assumed to boost the learning of the cue-behavior link beyond the impact of behavioural repetition (de Wit & Dickinson, 2009). In accordance with this assumption, prior research showed that intrinsic reward moderated the link between behavioral execution and automaticity of healthy nutrition behaviors (Judah et al., 2018; Wiedemann et al., 2014). That is, behavioral repetition of fruit and vegetable consumption (Wiedemann et al., 2014), and Vitamin C intake (Judah et al., 2018) were linked to higher automaticity particularly among participants who found the behavior to be intrinsically rewarding (Judah et al., 2018; Wiedemann et al., 2014). Findings at the between-person level, however, do not necessarily translate to the within-person level (Johnston & Johnston, 2013; Weyland et al., 2020).

Anticipated Regret

As a form of negative outcome expectancies, anticipated regret is conceived of as a motivator for positive healthy nutrition behaviors and as a facilitator of performance by linking consequences of inaction to aversive feelings of regret that individuals try to avoid (McEachan et al., 2011; Sorys & Byrka, 2017; Williams et al, 2018). Evidence from meta-analyses suggests that anticipated regret strengthens intentions and prompts behavioral execution of health behaviors, including healthy nutrition behaviors (Brewer et al., 2016; Ellis et al., 2018). For example, choice situations such as deciding over morning coffee whether to eat fruit or a doughnut for breakfast often lead individuals to resort to internal outcome representations (i.e., anticipated regret). When anticipated regret is linked to increased intention and behavioral execution, for instance, it could also be relevant for behavioral automaticity of a healthy nutrition behavior (Gardner, 2018).

Self-Efficacy

Another correlate of the adoption and maintenance of healthy nutrition behaviors is self-efficacy (Breland et al., 2020; Byrne et al., 2012; Lhakhang et al., 2014). Self-efficacy refers to individuals' beliefs about their capability to execute a new and/or challenging task (Bandura, 1997). It is assumed that self-efficacy plays a key role in increasing behavioral automaticity because self-efficacy entails components that may facilitate (e.g., confidence to make healthy nutrition choices, readiness for a dietary change) or inhibit (e.g., anxiety not to resist temptations of unhealthy food, obstacles for buying and preparing healthy food) habit formation (Pirolli, 2016; Wang et al., 2013). Yet, there is little empirical evidence on the link between self-efficacy and automaticity of food-related behaviors (Mergelsberg et al., 2020). In a recent study, self-efficacy was unrelated to automaticity of a novel food safety behavior (i.e., microwaving the kitchen sponge) at a three-week and four-week follow-up (Mergelsberg et al., 2020). Within-person relationships between nutrition-related self-efficacy and automaticity remain understudied.

Aims and Hypotheses of the Present Study

Studies that modelled daily (or finer timescale) fluctuations of automaticity contingent on daily variation of proposed intra-individual antecedents are rare. However, to examine *proximal* antecedents of automaticity of a healthy nutrition behavior (i.e., antecedents at stage 3 of the habit formation framework; Gardner et al. 2018), research designs that are sensitive to capture intra-individual changes of theory-based, psychological antecedents of automaticity are needed. This study, which presents secondary analyses of a larger randomized controlled trial (Keller et al., 2021), aimed to examine previous-day within-person (i.e., from one day to the next) relationships between antecedents (i.e., intrinsic reward, anticipated regret, and self-efficacy) and automaticity among participants who attempted to form a new nutrition habit across 85 days. Hypotheses were generated post-hoc after the registration of the main trial but were derived based on previous theory and evidence a priori our data analyses. In line with the habit formation framework (Gardner et al., 2018), we assumed positive associations between intrinsic reward, anticipated regret, and self-efficacy regarding a new and self-selected healthy nutrition behavior with automaticity of this behavior. The intrinsic reward value of a new healthy nutrition behavior was proposed to directly reinforce the cue–behavior relationships upon repetition and should therefore increase automaticity levels of the healthy nutrition behavior from one day to the next. Thus, we hypothesized that higher *within-person* intrinsic reward of the new healthy nutrition behavior on the previous day (H1a) would be linked with higher automaticity of the healthy nutrition behavior. We also hypothesized that higher within-person anticipated regret of not enacting the new healthy nutrition behavior on the previous day would be associated with higher automaticity of this behavior (H1b). Derived from past learning experiences, self-efficacy refers to the mental anticipation of one's capability to engage in future behavior and is thus assumed to have prospective effects on automaticity. Therefore, we hypothesized that higher within-person self-efficacy to enact the self-selected healthy nutrition behavior as planned on the previous day would be related to higher automaticity (H1c). Moreover, we explored short-acting effects of within-person intrinsic reward, anticipated regret, and self-efficacy on automaticity within a given day. Based on the literature reviewed above (e.g., Ellis et al., 2018; Mergelsberg et al., 2020; Wiedemann et al., 2014), we hypothesized that positive associations of *between-person* intrinsic reward (H2a), anticipated regret (H2b), and self-efficacy (H2c) with automaticity of a new healthy nutrition behavior would emerge. Additionally, an exploratory aim of the present study was to investigate changes in automaticity of a new healthy nutrition behavior over time as a function of within- and between-person intrinsic reward, anticipated regret, and self-efficacy (i.e., time x antecedent interactions).

Methods

Procedure

This study presents secondary analyses of a pre-registered randomized controlled trial (RCT), designed to examine effects of routine-based versus time-based action planning on automaticity of a healthy nutrition behavior among 192 German adults (Keller et al., 2021; https://www.drks.de; DRKS00016720). Detailed recruitment strategies, eligibility criteria, intervention procedure, and randomization procedure were reported elsewhere (Keller et al., 2021). During the initial baseline session (Day = 'D'; D0), participants provided informed consent, completed baseline questionnaires, and were randomly assigned to one of the two healthy nutrition-related planning intervention conditions (i.e., routine-based planning condition, or time-based planning condition). In both conditions, participants received general information about healthy nutrition behaviors and were advised to form a cue-behavior plan for one self-selected healthy nutrition behavior which should become their new habit across the following weeks or months. For this healthy nutrition behavior, participants in the routine-based planning condition were instructed to select a once-a-day and daily routine cue (e.g., after dinner), whereas participants in the time-based planning condition were asked to select a time cue (e.g., at 7 pm). At the end of the session, participants were asked to execute their self-selected healthy nutrition behavior, whenever their planned cue occurred. Brief end-of-day daily questionnaires were sent to participants across the subsequent 12 weeks (i.e., 84 days; D1-D84). The ethics committee of the first author's institution granted approval for this study (approval number: 226/2018).

Participants

Out of 204 adults who were assessed for eligibility, *N* = 192 adults (87% female) agreed to participate in the study and thus were enrolled and then randomized to one of the two conditions (routine-based planning condition: *n* = 96; time-based condition: *n* = 96). With reference to prior studies modelling habit formation (e.g., Lally et al. 2010) and recommendations in case of missing data in intensive longitudinal data (Bolger & Laurenceau, 2013), we excluded participants from final analyses who provided less than six daily assessments or did not respond beyond D60, leaving *n* = 135 adults (routine-based planning condition: *n* = 65; time-based condition: *n* = 70) for analyses (Lally et al., 2010). On average, participants were 24.8 (*SD* = 7.3, range: 18-56) years old and had a body mass index of 22.2 (*SD* = 3.7, range: 14-37).

Measures

Unless otherwise noted, data were collected daily between D1 (i.e., baseline assessment) and D85. As response format, 6-point Likert scales ranging from '*does not apply at all*' (1) to '*applies exactly*' (6) were used. Each day, participants were asked to first report their planned healthy nutrition behavior and cue (i.e., as planned in the intervention session at D0) and to refer to their planned behavior and cue when responding to subsequent items. Item examples provided below are translated from German.

Plan-Specific Automaticity (Hereafter 'Automaticity')

Daily self-reports of automaticity of the healthy nutrition behavior indicated habit strength of the novel healthy nutrition behavior. Automaticity was assessed with the self-reported behavioral automaticity index (SRBAI; Gardner et al., 2012; Verplanken & Orbell, 2003). The item stem '*My self-selected nutrition behavior is something*... ' was followed by four statements regarding automaticity (e.g., '*I do automatically'* or '*I do without thinking*'). Between-person reliability across 84 daily assessments was .99 (R_{KF}, Cranford et al., 2006) and within-person reliability was .89 (R_C, Cranford et al., 2006).

Plan-Specific Intrinsic Reward (Hereafter 'Intrinsic Reward')

Daily intrinsic reward of the healthy nutrition behavior was measured by three items: '*Executing my self-selected behavior feels rewarding to me*'; '*Executing my self-selected behavior is something I like to do*' and '*Overall, I am satisfied with the effects of my self-selected behavior*' (Wiedemann et al., 2014). Between-person reliability was .99 ($R_{KF,}$ Cranford et al., 2006) within-person reliability was .80 (R_C, Cranford et al., 2006).

Plan-Specific Anticipated Regret (Hereafter 'Anticipated Regret')

Daily anticipated regret of not enacting the healthy nutrition behavior was assessed by two items adapted from Abraham and Sheeran (2003) with the item stem '*If I will not execute my self-selected behavior tomorrow*…' followed by '*I would feel regret" and 'I would feel upset*'. Between-person reliability was .99 (R_{KF}, Cranford et al., 2006) within-person reliability was .86 (R_{C}, Cranford et al., 2006).

Plan-Specific Self-Efficacy (Hereafter 'Self-Efficacy')

To ensure comparability between participants and to account for the idiothetic nature of the self-efficacy construct (Scholz et al., 2005), we assessed self-efficacy to enact the healthy nutrition behavior as planned at the individual level (i.e., in relation to individuals' self-selected behaviors). Daily plan-specific self-efficacy was assessed with a single item: '*I am confident that tomorrow I will be able to perform my self-selected behavior exactly as planned*' (Scholz et al., 2005).

Covariates

The following baseline covariates were included: gender (0 = women, 1 = men), age, body-mass-index (BMI), and a dummy-coded intervention condition variable (0 = time-based planning condition; 1 = routine-based planning condition). To test effects of study variables on automaticity beyond effects of behavioral execution (Gardner et al., 2018), a within- and between-level plan enactment variable (reflecting execution of the planned behaviour) was used as an additional covariate.

Statistical Analyses

All data were analyzed using SPSS 25 (Wagner, 2019). Descriptive statistics, intraclass correlations (*ICCs*) as determined by unconditional means models (Singer & Willett, 2003) of study variables and their bivariate correlations were computed. To distinguish within- and between-person components, daily measures of intrinsic reward, anticipated regret, self-efficacy, plan enactment and automaticity were grand-mean and then person-mean centered (Bolger & Laurenceau, 2013). Whereas between-person components define the variation of participants' average levels around the samples' average (i.e., grand-mean), within-person components define the variation of each participants' daily levels around their own person average (i.e., person-mean).

To examine associations of previous-day within-person (time *t*-1) intrinsic reward, anticipated regret, and self-efficacy with same-day (time *t*) automaticity, we estimated lagged multilevel models with 84 study days nested in individuals according to propositions by Bolger and Laurenceau (2013), while adjusting for previous-day within-person automaticity as well as same-day within-person levels and between-person levels of intrinsic reward, anticipated regret, and self-efficacy, respectively. Models were fit using the SPSS MIXED function (Bolger & Laurenceau, 2013) with maximum likelihood estimation, treating missing data as missing at random, and implementing a first-order autoregressive error covariance structure. With reference to Keller et al. (2021), random effects of a linear time trend and a quadratic time trend were added to the model to control for time-dependent variation in automaticity. In all models, within-person parameters were allowed to vary randomly between participants and all possible random effects were modelled (Barr et al., 2013). Covariates were accounted for in all models.

Finally, we further explored changes in automaticity over time as a function of within- and between-person intrinsic reward, anticipated regret, and self-efficacy. An example model equation for Model I is presented in Appendix B.

According to recommendations for data analyses in field studies, the range of confidence intervals has not been adjusted for multiple testing (Moran, 2003; Nakagawa, 2004) and results are reported as point estimates at 90% confidence intervals in Appendix B.

Results

Descriptive Results

The analyzed sample (n = 135) did not differ from the enrolled sample (N = 192) on study variables, except for self-efficacy, which was higher in continuing participants (continuing participants: M = 4.7, SD = 0.7; dropped out participants: M = 4.5, SD = 0.8; n = 135; $t(101.26)$ = -2.01, p = .047). In the analyzed sample, participants answered 88% (M = 74.9, SD = 11.3, *range* = 19 -

85) of the 84 daily questionnaires. Most participants selected drinking water (*n* = 65; 48%; e.g., drink a glass of water when waking up) as their behavior to become a habit, followed by, consuming fruits (*n* = 32; 24%; e.g., eat an apple for breakfast), consuming vegetables (*n* = 8; 6%; e.g., eating one portion of vegetables for lunch), consuming mixes of fruits and vegetables (*n* = 11; 8%, e.g., drink a fruits and vegetables smoothie), or another nutrition behavior (*n* = 19; 14%; e.g., take a tablespoon of linseed oil). Descriptive statistics and unconditional *ICCs* among study variables are presented in Table 3.1. Automaticity was significantly and negatively correlated with BMI and age, and BMI was significantly negatively correlated with between-person anticipated regret and self-efficacy. On average, participants reported an automaticity level of 3.3 (*SD* = 1.2). The *ICC* of automaticity was 0.69, indicating that more than half of the total variance in overall automaticity of a healthy nutrition behavior was explained by between-person differences. Descriptive results of the correlates (scale from 1-6) showed mean levels of intrinsic reward (*M* = 4.4, *SD* = 0.9), anticipated regret (*M* = 3.7, *SD* = 1.2) and self-efficacy (*M* = 4.7, *SD* = 1.1).

Table 3.1

Means, Standard Deviations, and Intraclass Correlations of Study Variables

Variables	$Range_B$	M_B (SD_B)	SD_W	*ICC*	1	2	3	4
1 Automaticity	1-6	3.3 (1.2)	0.7	0.69	1	0.36**	0.07**	0.21**
2 Intrinsic reward	1-6	4.4 (0.1)	0.5	0.75	0.63**	1	0.31**	0.33**
3 Anticipated regret	1-6	3.7 (1.2)	0.6	0.73	0.40**	0.45**	1	0.31**
4 Self-efficacy	1-6	4.7 (1.1)	0.7	0.59	0.58**	0.63**	0.42**	1
5 Age	18-56	24.8 (7.3)			-0.13**	-0.02	-0.01	0.02
6 BMI	14-37	22.2 (37)			-0.11**	0.01	-0.03*	-0.05**

Note. Between-person correlations are shown below diagonal; within-person correlations above diagonal. M_b = mean at the between-person level, SD_b = standard deviation at the between-person, SD_w = standard deviation at the within-person level, *ICC* = Intraclass correlation, indicating the total variance that is explained by between-person differences as determined by unconditional means models using uncentered versions of the respective variables as outcomes (Singer & Willett, 2003), BMI and age were only available as between-person variables; BMI = Body-Mass Index; ** p < .01.

Main Effects of Proposed Within- and Between-Person Antecedents on Automaticity

Results of the three models testing previous-day within-person, same-day within-person, and between-person intrinsic reward, anticipated regret, and self-efficacy as correlates of automaticity are shown in Table 3.2. Contrary to our hypothesis (H1a), previous-day within-person intrinsic reward was not significantly related to automaticity. However, same-day within-person intrinsic reward was significantly related to automaticity, indicating that on days participants reported higher-than-usual intrinsic reward, they also reported higher levels of automaticity of a healthy nutrition behavior. In line with our hypothesis (H2a), a positive between-person intrinsic reward-automaticity link emerged, demonstrating that participants who reported higher average levels of intrinsic reward were more likely to report higher overall automaticity of a healthy nutrition behavior.

Contrary to our hypothesis (H1b) higher-than-usual anticipated regret on the previous day was not significantly associated with higher automaticity levels. However, same-day within-person anticipated regret was significantly related to automaticity of a healthy nutrition behavior, demonstrating that higher-than-usual anticipated regret was linked with higher automaticity within one day. As hypothesized (H2b), between-person anticipated regret was linked to higher automaticity levels, indicating that participants who reported higher overall levels of anticipated regret also reported higher overall automaticity.

Contrary to our hypothesis (H1c), previous-day within-person self-efficacy was not significantly related to automaticity of a healthy nutrition behavior, whereas same-day within-person self-efficacy was significantly linked to automaticity. In line with our hypothesis (H2c) between-person self-efficacy was significantly linked to automaticity, demonstrating that participants who reported higher overall levels of self-efficacy also reported higher automaticity of a healthy nutrition behavior.

Table 3.2

Associations of Same-Day Within-Person, Previous-Day Within-Person, and Between-Person Intrinsic Reward (Model I), Anticipated Regret (Model II), Self-Efficacy (Model III) With Automaticity

Outcome Automaticity	***Predictor: Intrinsic Reward***			***Predictor: Anticipated Regret***			***Predictor: Self-fficacy***		
Fixed Effects									
	***B*(*SE*)**	***p***	***CL*$_{95}$**	***B(SE)***	***p***	***CL*$_{95}$**	***B*(*SE*)**	***p***	***CL*$_{95}$**
Intercept	3.35 (0.06)	<.001	[3.21; 3.50]	3.33 (0.08)	<.001	[3.17; 3.48]	3.33 (0.07)	<.001	[3.18; 3.48]
Linear time	0.00 (0.00)	<.001	[0.00; 0.00]	0.00 (0.00)	<.001	[0.00; 0.01]	0.00 (0.0)	<.001	[0.00; 0.01]
Quadratic time	-0.00 (0.00)	<.001	[-0.00; -0.00]	-0.00 (0.00)	<.001	[-0.00; -0.00]	-0.00 (0.00)	<.001	[-0.00; -0.00]
Within-person automaticity (previous-day)	0.62 (0.02)	<.001	[0.58; 0.66]	0.63 (0.02)	<.001	[0.60; 0.66]	0.64 (0.02)	<.001	[0.52; 0.60]
Within-person predictor (same-day)	0.15 (0.02)	<.001	[0.11; 0.20]	0.08 (0.01)	<.001	[0.05; 0.10]	0.06 (0.01)	<.001	[0.03; 0.08]
Within-person predictor (previous-day)	-0.00 (0.01)	.846	[-0.03; 0.02]	-0.01 (0.01)	.450	[-0.03; 0.01]	-0.00 (0.01)	.789	[-0.01; 0.02]
Between-person predictor	0.58 (0.08)	<.001	[0.43; 0.73]	0.24 (0.07)	<.001	[0.07; 0.36]	0.54 (0.10)	<.001	[0.33; 0.76]
Within-person plan enactment (previous-day)	-0.06 (0.01)	<.001	[-0.08; -0.04]	-0.06 (0.01)	<.001	[-0.09; -0.04]	-0.06 (0.01)	<.001	[-0.09; -0.03]
Within-person plan enactment (same-day)	0.20 (0.01)	<.001	[0.18; 0.22]	0.21 (0.02)	<.001	[0.20; 0.24]	0.21 (0.02)	<.001	[0.17; 0.26]
Between-person plan enactment	1.08 (0.24)	<.001	[0.43; 0.73]	0.62 (0.35)	.074	[1.06; 2.12]	0.62 (0.35)	.074	[-0.15; 1.22]
Age	-0.01 (0.01)	.230	[-0.03; 0.01]	-0.01 (0.01)	.521	[-0.02; 0.02]	-0.01 (0.01)	.521	[-0.02; 0.01]
Sex	0.03 (0.03)	.275	[-0.02; 0.01]	0.04 (0.03)	.156	[-0.00; 0.10]	0.04 (0.03)	.156	[-0.01; 0.12]
Body-Mass-Index	-0.03 (0.02)	.113	[-0.06; 0.01]	-0.02 (0.02)	.218	[-0.07; 0.02]	-0.02 (0.02)	.218	[-0.06; 0.02]
Intervention condition	-0.0 3 (0.02)	.113	[-0.06; 0.01]	-0.02 (0.02)	.257	[-0.06; 0.02]	-0.02 (0.02)	.257	[-0.06; 0.02]

Random Effects ([co-]variances)									
Level 2 (between-person)	*Var* (*SE*)	*p*	***CL$_{95}$***	*Var* (*SE*)	p	***CL$_{95}$***	*Var* (*SE*)	*p*	***CL$_{95}$***
Intercept	0.54 (0.07)	<.001	[0.42; 0.69]	0.70 (0.09)	<.001	[0.56; 0.91]	0.65 (0.08)	<.001	[0.51; 0.84]
Linear Time	0.00 (0.00)	.002	[0.11; 0.20]	0.00 (0.00)	<.001	[0.00; 0.00]	0.00 (0.00)	<.001	[0.00; 0.00]
Within-person automaticity (previous-day)	0.03 (0.01)	<.001	[0.00; 0.00]	0.02 (0.00)	<.001	[0.02; 0.03]	0.02 (0.00)	<.001	[0.02; 0.04]
Within-person predictor (same-day)	0.03 (0.01)	<.001	[0.02; 0.05]	0.01 (0.00)	<.001	[0.01; 0.02]	0.01 (0.00)	<.001	[0.00; 0.01]
Intercept and within-person predictor (same-day)	0.06 (0.02)	<.001	[0.11; 0.20]	0.04 (0.01)	.003	[0.01; 0.06]	0.03 (0.01)	.021	[0.00; 0.04]
Within-person predictor (previous-day)	0.00 (0.00)	.123	[0.03; 0.10]	0.00 (0.00)	.048	[0.00; 0.01]	0.00 (0.00)	.038	[0.00; 0.01]
Intercept and within-person predictor (previous day)	-0.02 (0.01)	.320	[-0.05; 0.00]	0.01 (0.01)	.491	[-0.01; 0.03]	0.00 (0.01)	.823	[-0.01; 0.01]
Level 1 (within-person)									
Residual	0.11 (0.00)	<.001	[0.11; 0.12]	0.11 (0.00)	<.001	[0.11; 0.12]	0.11 (0.00)	<.001	[0.11; 0.11]
Autocorrelation	-0.24 (0.02)	<.001	[-0.27; -0.20]	-0.24	<.001	[-0.27; -0.20]	-0.24 (0.02)	<.001	[-0.27; -0.21]

Note. n = 135 participants, 84 days, 11340 diary days. *SE* = standard error. Time trends were z-standardized and centred at day 42 (D42) of the study. Random effects structure was reduced to allow for convergence of the model (i.e., no calculation of random effects for within-person plan enactment of the previous and the same day in all models)

[a] degrees of freedom were specified based on the number of subjects (N=135)

Results of a model including all three correlates to test unique effects of intrinsic reward, anticipated regret, and self-efficacy are displayed in Table 3.3. Results showed that all three same-day within-person correlates were uniquely linked to automaticity. That is, while controlling for the respective other correlates of automaticity of a healthy nutrition behavior, same-day within-person intrinsic reward, anticipated regret, and self-efficacy were positively related to automaticity. At the between-person level, intrinsic reward, but not anticipated regret and self-efficacy, showed unique links with automaticity of a healthy nutrition behavior.

Modelling Automaticity Over Time

Results on the relationship between the correlates x time interaction with automaticity are summarized here; result tables can be found in Appendix B (Table B.1). No significant automaticity relationships between the interaction of same-day within-person correlates (i.e., intrinsic reward, anticipated regret, and self-efficacy) with time parameters emerged (Table B.1). The increase of automaticity of a healthy nutrition behavior over time (i.e., linear time course in conjunction with a quadratic time course) was significantly moderated by between-person levels of intrinsic reward, anticipated regret, and self-efficacy. That is, participants who reported higher between-person intrinsic reward, anticipated regret, and self-efficacy regarding a healthy nutrition behavior showed a steeper initial increase in automaticity of a healthy nutrition behavior, which was followed by a flattened curve at high automaticity levels towards the end of the study (i.e., Figures B.1, B.2, B.3 in Appendix B).

Table 3.3

Competitive Test of Unique Links of Same-Day Within-Person, Previous-Day Within-Person, and Between-Person Intrinsic Reward, Anticipated Regret, and Self-Efficacy with Automaticity

Outcome Automaticity			
Fixed Effects (intercept, slopes)	***B* (*SE*)**	***p***	***CL_{95}***
Intercept	3.35 (0.07)	<.001	[3.22; 3.48]
Linear time	0.00 (0.00)	<.001	[0.00; 0.01]
Quadratic time	-0.00 (0.00)	<.001	[-0.00; -0.00]
Within-person automaticity (previous-day)	0.60 (0.02)	<.001	[0.60; 0.64]
Within-person intrinsic reward (previous-day)	-0.01 (0.01)	.648	[-0.03; 0.02]
Within-person intrinsic reward (same-day)	0.13 (0.02)	<.001	[0.09; 0.17]
Between-person intrinsic reward	0.47 (0.09)	<.001	[0.29; 0.65]
Within-person anticipated regret (previous-day)	-0.01 (0.01)	.534	[-0.02; 0.01]
Within-person anticipated regret (same-day)	0.04 (0.01)	.004	[0.01; 0.06]
Between-person anticipated regret	0.10 (0.07)	.143	[-0.03; 0.23]
Within-person self-efficacy (previous-day)	-0.01 (0.01)	.423	[-0.02; 0.00]
Within-person self-efficacy (same-day)	0.04 (0.01)	<.001	[0.02; 0.07]
Between-person self-efficacy	0.15 (0.12)	.201	[-0.08; 0.38]
Within-person plan enactment (previous-day)	-0.06 (0.01)	<.001	[-0.08; -0.04]
Within-person plan enactment (same-day)	0.19 (0.01)	<.001	[0.16; 0.20]
Between-person plan enactment	0.83 (0.31)	.008	[0.22; 1.44]
Age	-0.01 (0.01)	.474	[-0.02; 0.01]
Sex	0.03 (0.03)	1.00	[-0.03; 0.08]
Body-Mass-Index	-0.03 (0.02)	.104	[-0.06; 0.00]
Intervention condition	-0.03 (0.02)	.135	[-0.06; 0.01]
Random Effects ([co-]variances)	***Var* (*SE*)**	***p***	***CL_{95}***
Level 2 (between-person)			
Intercept	0.52 (0.06)	<.001	[0.41; 0.67]
Linear Time	0.00 (0.00)	<.001	[0.00; 0.00]
Within-person automaticity (previous-day)	0.03 (0.01)	<.001	[0.02; 0.04]

Within-person intrinsic reward (same-day)	0.02 (0.01)	<.001	[0.01; 0.03]
Intercept and within-person intrinsic reward (same-day)	0.03 (0.01)	.021	[0.00; 0.06]
Within-person anticipated regret (same-day)	0.01 (0.00)	.005	[0.00; 0.01]
Intercept and within-person anticipated regret (same-day)	0.02 (0.01)	.090	[-0.00; 0.04]
Within-person self-efficacy (same-day)	0.01 (0.00)	<.001	[0.00; 0.01]
Intercept and within-person self-efficacy (same-day)	0.02 (0.01)	.012	[0.00; 0.04]
Level 1 (within-person)			
Residual	0.11 (0.00)	<.001	[0.10; 0.11]
Autocorrelation	-0.23 (0.01)	<.001	[0.10; 0.11]

Note. n = 135 participants, 84 days, 11340 diary days. *SE* = standard error. Time trends were z-standardized and centred at day 42 (D42) of the study. Random effects structure was reduced to allow for convergence of the model (i.e., no calculation of random effects for the previous-day within-person intrinsic reward, anticipated regret, and self-efficacy, and within-person plan enactment of the previous and the same day)

[a] degrees of freedom were specified based on the number of subjects (N=135)

Discussion

Our study examined daily links of intrinsic reward, anticipated regret, and self-efficacy with automaticity of a healthy nutrition behavior within and between participants who planned to form a new healthy nutrition habit. Additionally, we examined how participants' daily automaticity levels of a new healthy nutrition behavior developed over time contingent on the other proposed behavioral antecedents' change over time (i.e., nutrition-related intrinsic reward, anticipated regret, and self-efficacy). Contrary to our hypotheses previous-day within-person intrinsic reward, anticipated regret, and self-efficacy were not significantly related with automaticity of a healthy nutrition behavior. However, higher-than-usual intrinsic reward, anticipated regret, and self-efficacy on the same day were associated with higher automaticity of a healthy nutrition behavior within the same day. Moreover, higher than average levels of intrinsic reward, anticipated regret, and self-efficacy (i.e., at the between-person level) were associated with higher overall automaticity, and, with a steeper initial increase of automaticity of a healthy nutrition behavior over time.

When controlling for the respective other proposed antecedents of automaticity of a healthy nutrition behavior, between-person intrinsic reward but not between-person anticipated regret and self-efficacy were positively linked to automaticity. It has to be noted that between-person levels of proposed antecedents were moderately correlated and thus might have shared variance in explaining automaticity of a healthy nutrition behavior. Between-person anticipated regret and self-efficacy were significantly negatively correlated with BMI in zero-order correlations, indicating that participants with lower BMI reported higher average levels of anticipated regret and self-efficacy. This is in line with prior findings suggesting that regret of nutrition behaviors inconsistent with healthy nutrition goals and self-efficacy for healthy dietary behavior facilitate engagement in weight-regulating behaviors (Dorling et al., 2019; Sorys & Byrka, 2021). Moreover, individuals were more likely to report lower automaticity levels when they were older and had a higher BMI. Older participants might have internalized the cue-behavior association to an overall lesser extent, given the ability to learn new associations declines with age (Howard & Howard, 2013). The finding that individuals with lower BMI reported higher levels of automaticity may point to the assumption that individuals with higher overall self-regulatory capacities more easily form healthy nutrition habits and in turn engage in more healthy nutrition behavior (Adriaanse et al., 2014). Likewise, the null-effects of BMI and age in the multilevel models suggest that the significant zero-order correlations of BMI and age with automaticity are confounded with self-regulating abilities, given that the multilevel models account for self-regulatory components (e.g., self-efficacy). Future research is needed to examine the role of individuals characteristics, such as age or BMI, in the formation of new healthy nutrition habits.

Links of Within-Person Proposed Antecedent With Automaticity

Overall, the results show that the previous-day proposed antecedents (i.e., intrinsic reward, anticipated regret, self-efficacy) were not predictive of automaticity of a healthy nutrition behavior and thus do not provide any evidence for our hypotheses.

Theoretically, learning the cue-response association is facilitated by experiencing intrinsic reward at the moment of the behavioral execution (Wood & Neal, 2007). In the present study, however, the proposed antecedents were self-reported some time after the cue was encountered (i.e., all questionnaires were filled out in the evening and the times of the day participants encountered their cues differed between participants) and may have not captured the extent to which participants experienced intrinsic reward, anticipated their regret, or felt self-efficacious at the time they enacted the behavior. That is, for instance, prior studies found that although the actual consumption of healthy food was linked to higher intrinsic reward than the consumption of less healthy food (White et al., 2013), healthy food was mostly considered to be less rewarding than unhealthy food (Raghunathan et al., 2006). Similarly, anticipated regret and self-efficacy are likely to address components which are highly malleable by situational influences (e.g., the impulse to avoid regret, or the level of confidence to make a healthy food choice in the face of nutrition-related temptations; Pirolli et al., 2016). To test whether intrinsic reward, anticipated regret, and self-efficacy strengthen the cue-behavior learning, future research is required that assesses event-based measures at the same time participants encounter the cue that either triggers the decision to enact a healthy nutrition behavior or the execution of the healthy nutrition behavior itself.

Same-day within-person intrinsic reward, anticipated regret, and self-efficacy were associated with automaticity, suggesting that the proposed antecedents had only short acting associations with automaticity of a healthy nutrition behavior. Evidence shows that positive emotional states are related to more heuristic, automatic processing of information, while negative emotional states are related to more systematic processing with higher vigilance (Tiedens & Linton, 2001). Thus, if a healthy nutrition behavior (e.g., preparing and eating vegetables for dinner) is experienced as intrinsically rewarding it may be more likely to be prepared and eaten with less conscious deliberation and therefore be executed more automatically at the given time. Likewise, higher experienced automaticity may have led to reports of higher self-efficacy to enact the self-selected healthy nutrition behavior. According to social cognitive theory, representations of self-efficacy emerge from experiences in self-regulation (Bandura, 1997) and high behavioral automaticity is associated with successful and effortless self-regulation which consequently may have led to reports of higher self-efficacy. For example, the assessment of one's self-efficacy to eat an apple for lunch on a daily basis, stems from memories of past experiences of the same or similar nutrition behaviors. If eating an apple for lunch is executed automatically, i.e. without effort, this experience should contribute directly to the assessment of one's self-efficacy to eat an apple for lunch the next day. In the current study, we measured all variables daily through the same questionnaire sent to study participants every evening. Consequently, same-day within-person effects do not allow for any inferences about temporal order in associations of the variables.

We found that anticipated regret was linked to higher same-day automaticity of a healthy nutrition behavior. Given that anticipated regret was previously shown to strengthen intentions (Brewer et al., 2016; Ellis et al., 2018) and increase decision quality (i.e., toward more goal-directed decisions, Zeelenberg & Pieters, 2007) it may play a particularly important role within the process of habitual behavior instigation (i.e., arriving at a decision to enact a behavior without conscious thought, Garder et al., 2016). That is, unstable intentions towards a healthy nutrition behavior are likely to prompt conscious deliberation (e.g., weighing pros and cons) for the individual before deciding in favour of the healthy nutrition behavior. Factors that bind individuals to their intentions to enact the healthy nutrition behavior may drive decisions to higher automaticity levels and increase instigation habit strength over time. However, this study did not differentiate between habitual behavior instigation and habitual behavior execution (Gardner et al., 2016) and the role of anticipated regret for instigation habit strength of healthy nutrition behaviors still needs to be examined.

Links of Between-Person Proposed Antecedents and Automaticity

At the between-person level, higher than average levels of intrinsic reward was associated with higher automaticity levels of a healthy nutrition behavior, which was expected and in line with previous findings (Judah et al., 2018; Wiedemann et al., 2014). Intrinsic reward of a healthy nutrition behavior is linked to higher probability of behavioral execution (Wiedemann et al., 2014) and might therefore also be linked to higher automaticity levels of the healthy nutrition behavior. Although in the present study we controlled for within- and between-person plan enactment (as a measure for cue-related behavioral execution of the healthy nutrition behaviors), and thus demonstrated that intrinsic reward is linked to automaticity over and above behavioral repetition, we cannot yet draw any conclusions about the mechanisms linking intrinsic reward of a healthy nutrition behavior to automaticity of this behavior. Higher average levels of anticipated regret and self-efficacy were associated with higher levels of automaticity. However, these links disappeared when controlling for the other proposed antecedents (i.e., intrinsic reward, self-efficacy), respectively. Likewise, we found that higher average self-efficacy was inconsistently linked with higher overall automaticity of a healthy nutrition behavior mirroring previous empirical findings that found positive links (Raison et al., 2020) as well as no association (Mergelsberg et al., 2020) with automaticity. It remains unclear whether nutrition-related anticipated regret and self-efficacy are directly linked with automaticity of a healthy nutrition behavior or whether other affect-related factors (e.g., intrinsic reward, actual experience of regret) or volitional factors (e.g., action control; Sniehotta et al., 2005) are involved.

Overall, intrinsic reward was the most consistent proposed antecedent yielding unique links with automaticity of a healthy nutrition behavior while controlling for self-efficacy and anticipated regret. Thus, experiencing the nutrition behavior as more rewarding may be more important for forming a healthy nutrition habit than conscious expectations of regret and personal beliefs about ability to enact the healthy nutrition behavior.

Increases of Automaticity Over Time as a Function of Intrinsic Reward, Anticipated Regret, and Self-Efficacy

Current study findings on the relationships of between-person intrinsic reward, anticipated regret, and self-efficacy support their beneficial role in the process of forming a healthy nutrition habit. Analyses of automaticity over time as a function of proposed antecedents demonstrate that higher average nutrition-related intrinsic reward, anticipated regret, and self-efficacy are particularly important for gains in automaticity of a healthy nutrition behavior at the beginning of the habit formation process, as study participants showed steeper initial increase with a flattened curve for later days of the study. This suggests that all three antecedents are relevant for forming a healthy nutrition habit. Future interventions may specifically examine whether targeting people with initially lower intrinsic reward, anticipated regret, and self-efficacy by intervening to improve these antecedents supports habit formation.

Study Strengths and Limitations

The current study had several strengths: we applied a research design that was sensitive to intra-individual changes of proposed antecedents and automaticity of a novel nutrition behavior over short temporal cycles. To the best of our knowledge, this was the first study that examined intrinsic reward, anticipated regret, and self-efficacy as potential antecedents of automaticity on a daily basis over more than two months. Our study shed light onto prospective (previous-day) and concurrent (same-day) links of proposed antecedents of automaticity of a healthy nutrition behavior. We also monitored study participants for up to 84 days that should be a sufficient time period to allow the participants to form healthy nutrition habits (Lally et al., 2010). However, the current study also had some limitations. As indicated by ICCs determined by unconditional means models of the study variables (Singer & Willett, 2003), the study participants showed little within-person variance in proposed antecedents and previous literature suggested that high within-person variance allows for higher precision in the results and their interpretation (Kwasnicka & Naughton, 2020). Measures in the present study were developed for studying between-person differences and thus may have limited utility when used to detect change within individuals over time (Hays & Hadorn, 1992; West et al., 2010). Additionally, we only assessed self-reports, whereas current technologies allow for real life habit formation monitoring using devices and sensors such as cameras, motion detectors placed in participants homes (Diefenbacher et al., 2020; Kwasnicka et al., 2019). Also, causal conclusions cannot be established as data were correlational. Future research should use experimental designs to manipulate, for instance, how intrinsically rewarding a nutrition behavior is perceived, and test subsequent habit formation.

Conclusions

This was the first study to assess intrinsic reward, anticipated regret, and self-efficacy as potential antecedents of automaticity, assessing their day-by-day relationships with automaticity of a new healthy nutrition behavior. Our results demonstrated that there is a strong relationship between each of these three constructs and automaticity when assessed at the same time, but not at a one-day time lag. Intrinsic reward showed unique links with automaticity and habit formation interventions could be particularly targeting the improvement of intrinsic reward to, in turn, support the formation of a new nutrition habit. Overall, future research should use similar approaches of intensive longitudinal methods to examine antecedents of automaticity at the between and within levels.

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Chapter 4: Toward more active commuting habits (Study 3)

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The accepted version of this article is not included in the online version.

Chapter 5:
General Discussion

General Discussion

Sustaining positive health behaviors over the long term is crucial for preventing, managing, and rehabilitating chronic illnesses (Dominguez et al., 2021; Hu et al., 2024). Habits, defined as context-response associations where encountering the context is proposed to automatically trigger a behavioral response, are assumed to support behavioral maintenance by guiding behavior automatically (Gardner & Lally, 2023). More complex health behaviors, such as physical activity or healthy nutrition, have also been shown to be at least partially guided by habits (Lally et al., 2010; Gardner et al., 2021). Habits are assumed to facilitate behavioral maintenance as a learned context should trigger a behavioral impulse despite lowered intention strength (Gardner et al., 2020). However, old, unwanted habit associations can also present barriers to behavior change (Verplanken et al., 2018). To support people in habitually practicing healthy behaviors and replacing unhealthy habitual behaviors with healthier alternatives, the present thesis examined the role of habit in complex health behaviors and examined theoretical determinants of habit formation and decay in real-life settings.

The primary objectives of this thesis were to examine how reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding complex health behavior (RQ 1); describe change trajectories of habit formation and its determinants (RQ 2); and describe change trajectories of habit decay and its determinants (RQ 3).

The empirical findings from Studies 1-3 are summarized in the following section and integrated into the existing literature to address the research questions of this thesis. Subsequently, the strengths and limitations of the studies are discussed, implications for future theory, research methods, and practice are outlined, and a final conclusion is presented. Table 5.1 outlines a summary of the research findings of this thesis with respect to its overarching research questions.

Table 5.1

Summary of the Empirical Studies' Findings With Respect to the Overarching Research Questions

Research Questions	Studies	Empirical Findings	Conclusion
How do reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding complex health behavior?	*Study 1*	The link of within-person intention strength and physical activity was moderated by between-person habit strength. That is, when average habit strength was high, lower than usual intentions were unrelated to physical activity levels. Within-person spontaneous action planning was positively linked to physical activity independent of between-person habit strength.	The findings suggest that complex health behavior, for which high habit strength is reported, is guided by a combination of reflective processes and habit. That is, strong habits can compensate for low intention, rendering within-person fluctuations in intention strength irrelevant for the engagement in complex health behavior. Spontaneous action planning remains an important reflective strategy for engagement in complex health behavior, regardless of habit strength.
How do habits form over time and what factors facilitate habit formation in real-life settings?	*Study 2*	Shapes of habit strength trajectories of a healthy nutrition behavior followed a quadratic time trend and varied as a function of between-person levels of intrinsic reward, anticipated regret, and self-efficacy. Same-day but not previous-day within-person intrinsic reward, anticipated regret, and self-efficacy were positively linked to habit strength of a healthy nutrition behavior.	The findings suggest that in the context of habit formation as well as substitution habit strength increases more rapidly in the early phases, with slower increase in later phases. Every opportunity to engage in the new behavior seems to be crucial when substituting habits. The momentary reward experienced upon behavioral performance appears to capture the aspect of reward associated with habit strength, rather than positive affective judgments reported at a greater temporal distance from the behavior. Moreover, stronger alignment than usual between reflective processes and habit correlates with more automatic execution of the behavior and a certain average degree of alignment of reflective processes and habit seems necessary in order to form healthy habits.
	Study 3	In the context of habit substitution, increase in habit strength of a new commuting behavior followed a quadratic time trend. Within-person plan enactment and within-person experienced reward were positively linked to habit strength of a new commuting behavior.	
How do habits decay over time and what factors facilitate habit decay in real-life settings?	*Study 3*	Habit strength of the old commuting behavior declined linearly. Within-person experienced regret (at $p<.10$) and between-person plan enactment were linked to lower habit strength of the old commuting behavior. At the end of the study period, habit strength of the old commuting behavior was lower compared to the habit strength of the new commuting behavior.	Findings suggest that habit strength of an old, unwanted habit decreases, at least partially, when substituted with a new, wanted alternative in the same context. Findings suggest that consistent, context-dependent repetition of a new, wanted behavior, as well as more negative experiences than usual associated with the old, unwanted habitual behavior, are correlates of habit decay.

Integration Into Theory and Empirical Findings

The following section summarizes the main findings of the empirical studies with respect to the research questions and integrates them into the literature.

The Interplay of Reflective Processes and Habit in Guiding Health Behavior

The first aim of this thesis was to examine how reflective processes (i.e., intention strength and spontaneous action planning) and habit interact when guiding complex health behavior (RQ 1). Findings suggest that complex health behavior is guided by a combination of both reflective processes and habit, when individuals report high habit strength for that behavior.

Consistent with the habit-intention interaction hypothesis (Verplanken & Wood, 2006), strong habit strength appeared to compensate for lowered within-person intention strength. However, within-person spontaneous action planning was a significant correlate of physical activity regardless of participants' habit strength (*Study 1*).

The results align with the assumption that habits in complex health behavior, such as physical activity, contribute to the automatization of specific sub-actions rather than enabling the entire behavioral sequence to be performed fully automatically (Hagger, 2016). Accordingly, it was recently proposed that more complex health behaviors are assumed to be always guided by a combination of reflective processes and habit (Gardner, 2024; Phillips & Mullan, 2023).

Given, that any behavior can be divided into an arbitrary number of sub-actions, each of which may be performed with varying degrees of habit strength, it was found to be a practically meaningful approach to distinguish between habits that initiate an action phase by guiding the automatic decision or commitment for a behavior (i.e., instigation habits) and those that automate the execution of the action itself (i.e., execution habits; Gardner, 2022). The physical activity habits might have played a role in the instigation of behavior rather than in the execution, even if not explicitly assessed as instigation or execution habits (*Study 1*). That is, for example, the decision or commitment to go running on Mondays might have been triggered automatically by the act of getting out of bed on Monday morning, despite lowered intention strength that morning (i.e., instigation habit; Gardner, 2022). However, executing this decision might have yet required adaptation to a flexible work schedule or the need to coordinate childcare or household tasks with a partner, which in turn would necessitate some degree of adaptive reflective processing, such as spontaneous action planning.

Even if complex behaviors may never be completely habitual, habits can support behavioral performance in the long term if sub-actions that are crucial for behavioral frequency are automatized. Prior evidence showed that habitual instigation but not habitual execution was linked to behavioral frequency, independent of behavioral complexity (Gardner, 2022). Behavioral complexity, however, appeared to be associated with the speed at which instigation habits formed, with instigation habits of more complex health behaviors potentially taking longer to establish (Buyalskaya et al., 2023).

Habit Formation and its Determinants

The second aim of this thesis was to examine how habits form and what factors facilitate habit formation (RQ 2). The results of *Study 2* and *Study 3* reported in this thesis suggest that habit strength – in the context of habit formation as well as substitution – increases more quickly in earlier phases whereas the increase is less pronounced in later phases. With respect to the theoretical determinants of habit formation at the within-person level, the findings highlight the importance of each opportunity to engage in the new behavior when substituting habits. Moreover, the results suggest that the immediate experience of reward upon performing the behavior plays a role at Stage 3b of the habit formation framework (Gardner & Lally, 2018), rather than positive affective judgments reported at a greater temporal distance from the behavior. Moreover, stronger alignment than usual between reflective processes and habit is linked to more automatic execution of a behavior on a given day.

Habit Formation Trajectories. The shape of habit formation trajectories, characterized by a more rapid increase in earlier phases and a less pronounced increase in later phases, was observed in both the context of habit formation (*Study 2*) and the context of habit substitution (*Study 3*). This mirrors findings from previous habit formation studies across various behavioral domains, such as physical activity and healthy nutrition, suggesting that the shape of habit formation trajectories may be similar across different behavioral domains (Fournier et al., 2017; Lally et al., 2010).

Context-Dependent Repetition. The findings demonstrated that – in the context of habit substitution – every single opportunity to engage in the new behavior was crucial for forming habits (*Study 3*), which is in line with previous propositions that habits form upon behavioral repetition (Gardner & Lally, 2018). Which pattern of context-dependent repetition might most effectively facilitate habit formation likely depends on the frequency with which the behavior is performed within a given time period. For infrequent behaviors, such as those performed only once per day (e.g., commuting to work), each opportunity to engage in the behavior appeared to play a more significant role for increases in habit strength (e.g., *Study 3* and Kilb & Labudeck, 2020). Conversely, for behaviors with multiple opportunities for enactment, such as those performed several times a day (e.g., disrupting sedentary behavior), single opportunities for behavioral engagement seemed to be less critical for the overall habit formation process (Lally et al., 2010).

Moreover, in the context of habit substitution, each behavioral repetition may be particularly important for increasing habit strength within persons, as inconsistent performance of the new behavior could allow the old habit to resurface and potentially regain strength, thereby hindering the formation of the new habit (*Study 3*).

Intrinsic Reward. The results suggest that in-the-moment experiences of reward were directly linked to increased habit strength upon behavioral performance (*Study 3*). More cognitive positive affective judgments showed inconsistent links, where same-day but not previous-day measures were positively linked to habit strength (*Study 2*). This finding aligns with prior research that reported same-day correlations between positive affective judgments of the behavior and habit strength but found no prospective associations from one day to the next (Kilb & Labudeck, 2022).

Theoretically, intrinsic reward is proposed to facilitate the learning of the context-response link when forming a habit (Gardner & Lally, 2018). However, a more differentiated description of the specific type and assessment of reward that is supposed to reinforce habit strength is needed (Kaushal et al., 2017). That is, experienced reward reported upon behavioral performance, as assessed in *Study 3*, rather captures the immediate positive affective response elicited by the behavior (Ekkekakis et al., 2013). In contrast, intrinsic reward, as assessed in *Study 2* and by Kilb and Labudeck (2022), referred to a positive affective judgment that represents the overall anticipated pleasure or enjoyment associated with engaging in the behavior (Rhodes et al., 2009). Affective evaluations of a behavior do not always correspond to the immediate affective response it elicits, especially when affective judgments are reported with a temporal delay to the behavior (Rhodes et al., 2023; Woolley & Fishbach, 2017). It is conceivable that the same-day measures of intrinsic reward in *Study 2* more closely reflected the affective response to the behavior performed on the same day compared to the previous-day measures.

Recent theoretical perspectives further refine understanding the role of experienced reward in habit formation by suggesting that positive affective responses enhance habit learning only when they exceed expectations, producing a so-called reward prediction error (Perez & Dickinson, 2020). For example, if a healthy nutrition behavior is judged to be intrinsically rewarding on one day and is experienced as equally rewarding the next day, increase in habit strength should not be more pronounced. However, if the behavior is perceived as more rewarding than expected (e.g., cycling to work feels unexpectedly enjoyable), the learning of the context-response association should be reinforced (Perez & Dickinson, 2020).

Momentary measures, but not positive affective judgments assessed with greater temporal distance from the behavior, appear to capture the reward value correlated with habit strength within-persons over and above behavioral repetition (i.e., stage 3b of the habit formation framework, Gardner & Lally, 2018).

Reflective Processes. The findings of this thesis demonstrated that stronger alignment between reflective processes (i.e., anticipated regret and self-efficacy) and habit was correlated with smoother automatic behavioral execution but was not prospectively linked to higher habit strength

(*Study 2*). Yet, certain minimum average alignment between reflective processes and habit appeared to be necessary in order to form new habits (*Study 2*).

Anticipated regret and self-efficacy were demonstrated to bind individuals to their intentions and reduce the need for self-regulatory efforts (Breland et al., 2020; Ellis et al., 2018). On days when these processes were more pronounced, the reflective system and the habitual impulse should be more likely to work synergistically yielding more fluent and smooth behavioral execution (Strack & Deutsch, 2004). Conversely, on days when these processes were less pronounced, individuals may engage in heightened reflective processing, which is assumed to disrupt the automatic performance of behaviors (Wood & Neal, 2007). Unstable intentions or low self-efficacy to engage in a healthy nutrition behavior, for instance, may prompt reflective processing, such as weighing pros and cons, thereby interrupting the automatic performance of a healthy nutrition behavior.

Moreover, findings point to the assumption that higher average levels (i.e., between-person) seem to be a pre-requisite for participants to form healthy habits at all, independent of context-dependent repetition. That is, those participants with lower average levels of reflective processes showed slower increases in habit strength, leveling off at lower maximum levels and thus failing to form healthy nutrition habits, as their habit strength remained below the scale midpoint within the study period while context-dependent behavioral frequency was controlled for (*Study 2*). In a similar vein, prior research demonstrated that healthy habits formed only among participants who reported high average levels of intrinsic motivation for the new behavior (Gardner & Lally, 2013).

Habit Decay and its Determinants

The third aim of this thesis was to examine how habits decay and what factors facilitate habit decay (RQ 3). Results suggest that old, unwanted habits decay slowly and persist in part, even if the old habitual response is largely substituted by a new behavior. Decay in habit strength seems to be associated with overall more consistent repetition of the new behavior in the same context and with higher than usual negative experience of the old, unwanted habitual behavior.

Trajectories of Habit Decay. The findings of this thesis demonstrated a linear decline in the habit strength of an old, unwanted commuting habit. However, this decrease was gradual, and the old habit strength persisted to some extent until the end of the study period (*Study 3*). This finding aligns with the assumption that habit strength decreases as the old habitual behavior diminishes (Keller et al., 2021; Walker et al., 2015), as well as with the notion that old habit strength may never be fully unlearned (Bouton, 2000). Additionally, the results support Gardner et al.'s (2021) proposition that habit substitution may modify underlying context-response associations.

Opposed to findings of the present thesis, a recent intensive longitudinal study by Edgren et al. (2024) that modeled habit decay over 91 days found a non-linear trajectory of habit decay. Similar to the typical shape of habit formation trajectories, habit decay in this study was characterized by a rapid decline in the earlier stages, which then stabilized at a lower level bound (Edgren et al., 2024).

In the present thesis, habit substitution appeared successful for the average participant by the end of the study (*Study 3*), as the habit strength of the new behavior was relatively stronger than of the old behavior. Consequently, the new habitual response should therefore more likely override the weaker old habitual impulse in the long-term (Lally & Gardner, 2013).

Context-Dependent Substitution. Overall consistent engagement in the new, healthier commuting behavior was associated with a decline in the habit strength of the old commuting behavior (*Study 3*). This supports prior findings from a simulation study that showed habit decay to require consistent substitution by an alternative response (Tobias, 2009). Although context-dependent repetition of the new commuting behavior remained high throughout the post-intervention period, the decline in the old habit's strength was relatively slow, suggesting that substituting established habits may require sustained repetition of the alternative behavior over extended periods of time (*Study 3*).

Experienced Regret. Findings from this thesis demonstrated that higher than usual experienced regret tended to be linked to habit strength of the old commuting behavior (i.e., at $p < .10$; *Study 3*). Opposed to predictions of the devaluation paradigm, which posits that established habits persist independent of experienced outcomes (Watson et al., 2023), aversive experiences seemed to play a role in the decay of old, unwanted habit strength (*Study 3*). In a similar vein, empirical evidence from more controlled settings (e.g., animal studies, human laboratory studies) casted doubt on the view that habitual behaviors can gain independence from consequences of the behaviors (Bouton, 2024; De Houwer, 2019a, 2019b).

Strengths and Limitations

In the following section the strengths and limitations of the empirical studies reported in this thesis are outlined below.

Strengths

The findings of *Study 1* expand prior empirical evidence on the habit-intention interaction hypothesis that lacked repeated measures to capture typical within-person fluctuations in intention strength over time (Gardner et al., 2020). Furthermore, to support individuals in forming healthy habits, requires an understanding of what drives habit change within individuals (Gardner & Lally, 2018). A significant strength of *Study 2* and *Study 3* was that links of within-person fluctuations of theoretical determinants of habit strength were examined.

Moreover, this thesis analyzed data from three longitudinal studies with repeated assessments over time, spanning 12 weeks (*Study 2*), 14 weeks (*Study 3*), and one year (*Study 1*). The extended measurement periods represent a significant strength of this thesis, as they were sufficient to capture longitudinal changes in individuals' reflective processes (i.e., intention strength and spontaneous action planning), habit strength, and theoretical determinants of habit change over time (Lally et al., 2010; Sheeran et al., 2017).

The large sample sizes in *Study 1* and *Study 2* are a notable strength, as they enhance the statistical power, reliability, and generalizability of the findings (Andrade et al., 2020). Across all studies, attrition rates were low making the data less prone to biases due to selective participant dropout.

Another strength is the measurement of both the habit strength of the new behavior and the old behavior in *Study 3*, representing one of the first investigations of habit substitution processes in real-life settings.

Limitations

The studies reported in this thesis also had several shortcomings that are discussion below and sorted by measurement of habit strength, samples and attrition, study designs, and data analyses.

Measurement of Habit Strength. Habit strength was measured with the self-reported behavioral automaticity index (SRBAI; Gardner et al., 2012; Verplanken & Orbell, 2003) in all studies. However, self-reports may have solely captured a subjective experience of behavioral automaticity in a specific context (e.g., perceived 'fluency' or lack of awareness in executing the behavior), rather than the habit strength, i.e., strength of an internalized context-response association (Hagger, 2019). A recent meta-analysis that examined patterns of habit-behavior links found, however, that self-reported habit strength demonstrated the theoretically expected differential effects on behavior (e.g., independent from intention, mediation of past-future behavior links) suggesting adequate assessment of habitual behavior by the SRBAI (Hagger et al., 2023).

Moreover, in all studies, automaticity was assessed regardless of whether the associated behavior was performed that same day, which may have biased the self-reports (Mazar & Wood, 2022). This might have especially affected automaticity levels of the old commuting behavior in *Study 3*, which was rarely performed during the post-intervention period. Nevertheless, it is conceivable that participants can perceive changes in habit strength without performing the behavior, for instance, when suppressing or redirecting impulses from the established habitual response (Edgren et al., 2024).

Samples and Attrition. Participants in *Study 1* were 225 healthy couple members of which about half were female and on average 38.37 years old (range: 19–78). As compared to the general population, the participants were highly physically active adults all living in longer-term romantic relationships (Knoll et al., 2017; Keller et al., 2020; Pauly et al., 2020). Thus, generalizability of the findings to inactive adults or those who do not live in relationships is constrained. However, high physical activity levels made this sample well-suited for examining factors that support the sustained maintenance of healthy behaviors.

Study 2 analyzed data from 135 adults (87% female) with a mean age of 24.8 years (range: 18–56) and only included individuals who were motivated to form a healthy nutrition habit. The predominance of female participants might reflect prior findings that women generally show greater interest and motivation for healthy eating behaviors (von Bothmer & Fridlund, 2005), thereby limiting the generalizability of the results to other genders or less motivated individuals. It can be argued, however, that strong intentions for a behavior is always a prerequisite for habit formation, given that context-dependent repetition is unlikely without sufficient motivation (Gardner & Lally, 2018).

Study 3 included 42 participants (60% female) with a mean age of 32.2 (range: 18–63). The small sample size yielded analyses clearly underpowered and replication of the results with a larger sample is required.

Study 2 and *Study 3* seemed to be selective for participants of younger age, which might have biased the results on habit formation. That is, the decline in cognitive functions, such as working memory and prospective memory, with age could reduce the ability to learn new context-behavior associations (Howard & Howard, 2013), but may also increase reliance on habits as a compensation strategy (van de Vijver et al., 2023).

Study Designs. In *Study 1*, psychological variables were assessed in up to five measurement points spanning one year. However, previous research suggests that intention, spontaneous action planning, and habit strength can fluctuate from day to day (Sonnentag et al., 2022, Jekauc et al., 2024) and assessments with even higher time resolution and in closer temporal proximity to behavioral performance, could allow for more valid tests of these variables and their interaction at the moment of behavioral performance (Rebar et al., 2014). Likewise, the daily end-of-day assessments in *Study 2* may have not fully captured in-the-moment experiences of proposed determinants and behavioral automaticity. Building on these insights, *Study 3* aimed to investigate the theoretical determinants of habit change using an event-based approach that was suitable to capture in-the-moment experiences (Shiffman et al., 2008). Although it was not possible to verify whether participants in *Study 3* consistently completed the questionnaire in the critical moment, which may have biased reporting of in-the-moment experiences, the study team made ongoing adjustments to the EMA prompt schedules to reflect changes in participants' commuting schedules.

Moreover, in *Study 3* the process of habit decay may have not been fully captured due to the limited number of opportunities for participants to substitute their new commuting behavior (i.e., once per day on five days a week). Visual inspection of changes in average habit strength in *Study 3* showed that decline in habit strength of the old commuting behavior seemed to be less pronounced in the later weeks of the study. However, no conclusions can be drawn on whether habit strength of the old commuting behavior would have continued, leveled-off, or increased beyond the study period.

Due to the non-experimental design of all three studies, causal relationships cannot be inferred from the results of the present thesis.

Data Analyses. The lagged multilevel models in *Study 2* tested prospective (previous-day) as well as concurrent (same-day) links of theoretical determinants and habit strength. Thus, the same-day links were purely correlational and do not allow conclusions about the direction of the association (*Study 2*). In *Study 3*, participants reported their outcome experiences upon arrival at work and their habit strengths at the end of the day. This time lag in data collection implied an underlying temporal directionality between the predictors and outcomes in the model. In contrast to *Study 2*, however, the models in *Study 3* were not controlled for autoregressive effects, potentially overestimating the association between within-person reward and regret and habit strength (Singer & Willett, 2003) and limiting the comparability of findings between *Study 2* and *Study 3*.

Implications for Theory, Research Methods and Practice

The following paragraphs offer theoretical, methodological and practical implications regarding the role of habit in health behavior change and its determinants.

Implications for Theory

The present thesis outlined context dependency and goal independence as the main characteristics of habit (Wood & Neal, 2007). Goal-independence refers to the assumption that habits should operate independently of a behavior's expected or experienced consequences (Wood et al., 2022). However, the observed association of negative outcome experience (i.e., experienced regret) and decline in old habit strength suggested that habits may not be entirely independent from behavioral consequences (*Study 3*). In a similar vein, experimental tests in controlled settings have failed to conclusively demonstrate that habits are independent of behavioral outcomes (de Houwer, 2019a, 2019b). While this may be due to the inherent interaction between the automatic and reflective systems (Strack & Deutsch, 2004), other theorists have challenged the assumptions of dual-process models, arguing that all behaviors, including habitual behaviors, are guided by one overarching goal-directed system (Tobias, 2009). Yet, a shared theoretical understanding of the conceptualization and defining characteristics of habits in complex health behaviors is lacking.

Moreover, the results of *Study 1* demonstrated that complex health behavior, such as physical activity, often involves a combination of habitual and reflective components. However, theoretical ambiguity persists regarding the conditions under which a behavior can be accurately characterized as 'habitual'. Originally, habitual behaviors were defined as single, automatic responses to a particular context (e.g., Wood & Neal, 2007). More recent perspectives, however, suggest broader conceptualizations. For instance, it was proposed that a behavior is habitual if it is instigated by an automatic impulse, even if performed consciously and flexibly (Phillips et al., 2019). Similarly, it was argued that a behavior can be conceptualized as habitual if it is either automatically instigated or executed (Gardner, 2024). These differing perspectives underscore the need for a more precise definition and conceptualization of habitual behavior in complex health behaviors.

Implications for Research Methods

In the following section, implications for future research are derived based on the results of the thesis.

The Interplay of Counter-Intentional Habits and Intentions. The thesis demonstrated that strong habits that are aligned with intentions can compensate for varying levels of intention strength (*Study 1*). However, it remains unclear how counter-intentional habits and intentions interact in guiding behavior in the long-term (Gardner et al., 2020). While evidence suggests that counter-intentional habits may dominate when self-regulatory capacities are impaired (Wood et al., 2016), intentions are generally expected to prevail over counter-intentional habitual responses in the long term (Gardner, 2024). Future research is needed to examine the extent to which established healthy habits sustain health behaviors in situations where the original intention for the healthy habitual behavior is reversed or no longer present.

The Role of Execution Habits for Behavioral Maintenance. The thesis demonstrated that action planning remains an important volitional strategy for maintaining physical activity, regardless of physical activity habit strength (*Study 1*). While spontaneous action planning allows for flexible and adaptive execution, it also makes behavioral maintenance reliant on self-regulatory resources (Sjåstad & Baumeister, 2018). Future research could investigate whether long-term behavioral maintenance is more effectively supported by focusing on building instigation habits that allow for flexible execution with some reliance on reflective processing or by helping individuals create a few efficient plans that can be – after sufficient context-dependent repetition – executed habitually.

The Role of Old and New Habits When Guiding Health Behavior. The results of the thesis indicated that old, unwanted habits decline slowly and only partially when substituted by new, healthier behavior (*Study 3*). Old, remaining habits that are not currently acted upon, referred to as "dormant habits" (Gardner et al., 2024), are thought to facilitate the re-emergence of old behavioral patterns following temporary disruptions. For example, Gardner et al. (2021) reviewed 26 qualitative studies on weight loss and found that familiar environments significantly increased the risk of relapse, even months after successful dietary changes. However, full relapse into old behaviors is typically driven by complex cognitive and emotional dynamics that undermine behavior change, rather than by simple context-response associations alone (Gardner et al., 2024; Dombrowski et al., 2010; Ten Broeke & Adriaanse, 2023).

More research is needed to examine to what extent old and under which circumstances, substituted habits actually re-install old behavioral patterns more easily (Gardner et al., 2024). Future studies could investigate how the relative strength of old and new habits predicts relapse versus maintenance patterns within individuals. Additionally, future research could examine how many repetitions of a previously substituted habitual behavior are needed for old habits to surpass the strength of the new habit or to trigger long-term relapse into old behavioral patterns. Moderating factors, such as context stability, availability of self-regulatory resources (e.g., stress, fatigue), and intention strength, should also be considered in understanding the link of old and new habit strength and behavior.

Experimental Tests of Theoretical Determinants. Outcome experiences were demonstrated to be associated with changes in habit strength (*Study 3*). However, findings of this thesis were only observational warranting replication using an experimental design. Future studies should investigate whether the experimental modulation of experienced reward or experienced regret facilitates changes in habit strength.

Implications for Future Practice

The following section outlines the practical implications based on the findings of this thesis.

Context-Dependent Repetition and Reflective Processes. Since the habit strength of new behaviors increased more rapidly in the initial stages (*Studies 2 and 3*), context-dependent repetition should be emphasized early in the behavioral adoption process. Furthermore, the thesis demonstrated that each opportunity of behavioral performance appeared to play a critical role in habit formation within the context of substituting habits (*Study 3*). When substituting habits, participants should be encouraged to capitalize on every opportunity to perform the new behavior in the same context. Additionally, the present thesis demonstrated that stronger alignment between reflective processes and habit correlated with higher behavioral automaticity and high overall alignment seemed necessary in order to form healthy habit while behavioral repetition was controlled for (*Study 2*).

Thus, to promote context-dependent repetition, habit-focused interventions should target goal-directed reflective processes that play a role at stage 1-3a of the habit formation framework (Gardner & Lally, 2018). Moreover, habit-focused interventions should support an overall high and sustained goal-directed state throughout the habit formation process. That is, for instance, habit-focused interventions could encourage individuals to select behaviors they are intrinsically motivated to perform or that reflect personal values and self-identity, which has been demonstrated to sustain motivation and behavioral engagement (Whatnall et al., 2021; Samdal et al., 2017). Moreover, interventions could incorporate booster intervention sessions to continuously reinforce motivation, for example by heightening awareness of the emotional and health-related consequences of the old and new behaviors (Walshnat et al., 2021; Samdal et al., 2017).

Experienced Reward. The findings of this thesis demonstrated that immediately rewarding experiences upon behavioral performance are linked to higher habit strength (*Study 3*). Habit-focused interventions should aim to enhance immediate rewards by encouraging individuals to identify and plan elements that increase experienced reward upon behavioral performance. For instance, practitioners could encourage individuals to engage in activities with others (Lüscher et al., 2022) or in natural environments (McMahan & Estes, 2015) which has been associated with greater enjoyment. Additionally, Just-in-Time Adaptive Interventions (JITAIs; Nahum-Shani et al., 2016) could prompt individuals to focus on positive feelings or sensations upon behavioral performance using strategies such as attention redirection or cognitive reappraisal (Clark, 2022).

Promotion of Instigation Habits. The results of the thesis demonstrated that behavior is guided by a combination of reflective processes and habit, and that habit primarily compensates for lowered intention, but not for lowered spontaneous action planning (*Study 1*). Given that habitual instigation (i.e., the automatic decision or commitment to engage in a behavior), rather than habitual execution (i.e., the automatic performance of a behavior), is associated with higher behavioral frequency (Gardner, 2022), habit-focused interventions should primarily aim to promote the formation of strong instigation habits. Furthermore, such interventions should also equip participants with reflective strategies, such as action planning, to support the adaptive and flexible execution of health behaviors that are habitually instigated.

Habit Substitution. Findings suggested that habit substitution was successful for the average participant following the one-arm online planning intervention (*Study 3*), which likely decreased the risk of relapse into old behavioral patterns (Gardner et al., 2021). The positive outcomes and the minimal resource requirements (i.e., remote, self-guided completion by the participants without contact to the study team, completion time was on average 16 minutes) of this one-arm online planning intervention indicate potential for scalability in future practice. However, replication using an experimental design is still required.

In line with prior research, which found that identifying specific contextual elements assumed to trigger the behavioral impulse is not a feasible strategy, identification of such elements was not included as behavior change technique in the one-arm online planning intervention in *Study 3* (Adriaanse & Verhoeven, 2018; Mazar & Wood, 2022). Instead, it was assumed, that commuting-to-work behaviors are triggered in stable contexts (e.g., before commuting) and, as a result, critical contextual elements of old and new commuting habits should significantly overlap (e.g., morning routines, cohabitants or family members, objects or locations in the apartment). This approach seems feasible where context stability across old and new behaviors naturally occurs. Thus, interventions targeting habit substitution should focus on leveraging stable contexts that naturally overlap between old and new behaviors, rather than attempting to identify specific contextual elements.

Conclusion

This thesis examined the role of habit strength in complex health behaviors and its determinants in real life settings. The following conclusions can be drawn for the respective research questions.

RQ 1 – How Do Reflective Processes (i.e., Intention Strength and Spontaneous Action Planning) and Habit Interact When Guiding Complex Health Behavior?

Complex health behaviors, for which individuals report high habit strength, are likely to be performed by an interplay of habitual and reflective processes. Healthy habits support engagement in complex health behavior when motivation fluctuates, as strong habits can compensate for reduced intention strength. Flexible reflective processes, such as spontaneous action planning, serve as important strategies for adaptive engagement in complex health behaviors, regardless of whether the decision to act is initiated habitually or reflectively.

The findings of this thesis, however, only refer to the case where habit and intention are aligned. Future research should explore the extent to which strong healthy habits sustain behavior in the absence of positive intentions.

RQ2 - How do Habits Form Over Time and What Factors Facilitate Habit Formation in Real-Life Settings?

Habits appear to form more rapidly during earlier stages, with a slower increase in later phases of the habit formation process. This pattern is consistent for both habit formation and habit substitution contexts. In the context of habit substitution, each opportunity to engage in the new behavior is important for establishing a new habit. Momentary experiences of reward seem to be more relevant for within-person increases in habit strength than affective judgments of rewards reported at a greater temporal distance from the behavior. These observations highlight the relevance of capturing immediate behavioral experiences when examining within-person variations in habit strength. Moreover, a certain degree of alignment between reflective processes and habit seems to be necessary in order to form new habits.

However, the present findings were correlational in nature and no causal conclusions can be drawn. Future research is warranted to replicate results using experimental designs.

RQ 3 - How do Habits Decay Over Time and What Factors Facilitate Habit Decay in Real-Life Settings?

The habit strength of old, unwanted behavior decreases when substituted by a new, wanted behavior. Although habit strength decays slowly and only partially, an old habit can be substituted by a new, healthier habit. Decrease in old habit strength is associated with consistently performing the new, wanted behavior in response to the old context. Additionally, immediate negative experiences of the old behavior seem to play a role in the decay of old habit strength.

However, the extent to which persisting old habit strength may increase the likelihood of relapse into old behavioral patterns remains to be examined. Future research should explore how changes in both old and new habit strength are linked to behavioral performance.

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Appendix A

Supplementary Material for Study 1

Measure	Items

Moderate-to-vigorous physical activity (MVPA): Reports on a list of physical activities with moderate-to-vigorous intensity

(Mader, Martin, Schutz, & Marti, 2006)

We would like to ask you about your physical activities during the past seven days. For each of the activities listed, please indicate:
Number of days you performed the activity during the past seven days
Average duration per day
Please think about your past 7 days and report on how many days and for how long (per day) you performed each activity.

Activities	During the past 7 days								
	Number of days								Average duration per day (in hours)
	0	1	2	3	4	5	6	7	
Fast uphill walking									0 . 1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10
Basketball									0 . 1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10
Fast bicycling (15 km/h)									0 . 1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10
Running									0 . 1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10
Swimming									0 . 1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10

[For illustration purposes, this table only lists five (out of 38) exemplary physical activities with moderate-to-vigorous intensity]

Intention strength

(Sniehotta, Schwarzer, Scholz, Schüz, 2005)

I intend to, …
be more physically active during everyday life (e.g., taking the stairs, housework, or gardening).
travel more frequently on foot or by bicycle.
be more physically active during my leisure time (e.g., swimming, walking).

Action planning

The following is about whether you have made concrete plans to increase your own physical activity in the last 7 days.

(Sniehotta et al., 2005)	During the past 7 days, I have made detailed plans, on ... when to be physically active. where to be physically active. how to be physically active. how often to be physically active.
Plan-specific self-efficacy	I am confident that I will be able to perform my behavior in the situation exactly as planned.
(Scholz et al., 2005)	
Plan-specific habit strength	Now please remember your habits of the last 7 days.
(Verplanken & Orbell, 2003)	Being physically active, as I have planned, is something.. I do automatically I do without having to consciously remember. I do without thinking . I start doing before I realize I'm doing it.

Note. For intention strength, action planning, and plan-specific habit strength items are accompanied by response scales anchored by "does not apply at all" (1) to "applies exactly" (6). For plan-specific self-efficacy scales anchored at "not true" (1) to "exactly true" (4).

References for Appendix A

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Appendix B

Supplementary Material for Study 2

Example model equation for Model I

Automaticity on day *d* for person *i*, automaticity$_{di}$ *was modelled (Model 1) as follows:*

Level 1: $automaticity_{di} = \beta_{0i} + \beta_{1i}(\text{previous-day automaticity}_{di})$

$+ \beta_{2i}(\text{previous-day plan-enactment}_{di})$

$+ \beta_{3i}(\text{same-day plan-enactment}_{di})$

$+ \beta_{4i}(\text{previous-day intrinsic reward}_{di})$

$+ \beta_{5i}(\text{same-day intrinsic reward}_{di})$

$+ \beta_{8i}(\text{StudyDay}_{di})$

$+ \beta_{9i}((\text{StudyDay})^2{}_{di}) + e_{di}$ (1)

with

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{average planenactment}_i)$

$+\gamma_{02}(\text{average intrinsic reward}_i)$

$+\gamma_{04}(\text{Age}_i)$

$+\gamma_{05}(\text{intervention condition}_i)$

$+\gamma_{06}(\text{BMI}_i)$

$+\gamma_{06}(\text{Sex}_i)+u_{0i}$ (2)

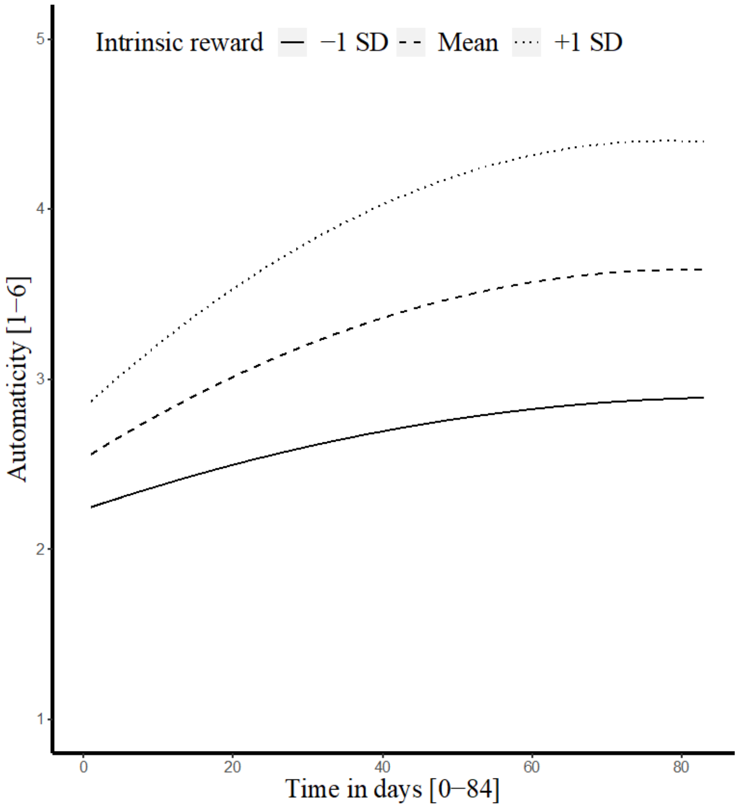
$\beta_{1i} = \gamma_{10} + u_{1i}$ (3)

$\beta_{(2-9)i} = \gamma_{(2-9)0}$ (4)

In this model, γ_{00} represents the samples average level of automaticity, γ_{01} to γ_{06} are the between-person links of the set of variables listed in the brackets with daily automaticity levels (automaticity$_{di}$), γ_{10} to γ_{90} resemble the strength of the within-person links across all participants between the set of variables listed in brackets and daily automaticity, and u_{01} and u_{1i} are residual deviations at the individual level that are independent of the residuals e_{di} at the day level. In this particular model, links between previous-day within-person intrinsic reward, same-day within-person intrinsic reward, and average (i.e., between-person) intrinsic reward are tested whereas previous-day within-person plan-enactment, same-day within-person plan-enactment, average (i.e., between-person) plan-enactment, age, BMI, group condition, sex and day in the study serve as statistical controls to reduce bias in estimates of the coefficients.

Figure B.1

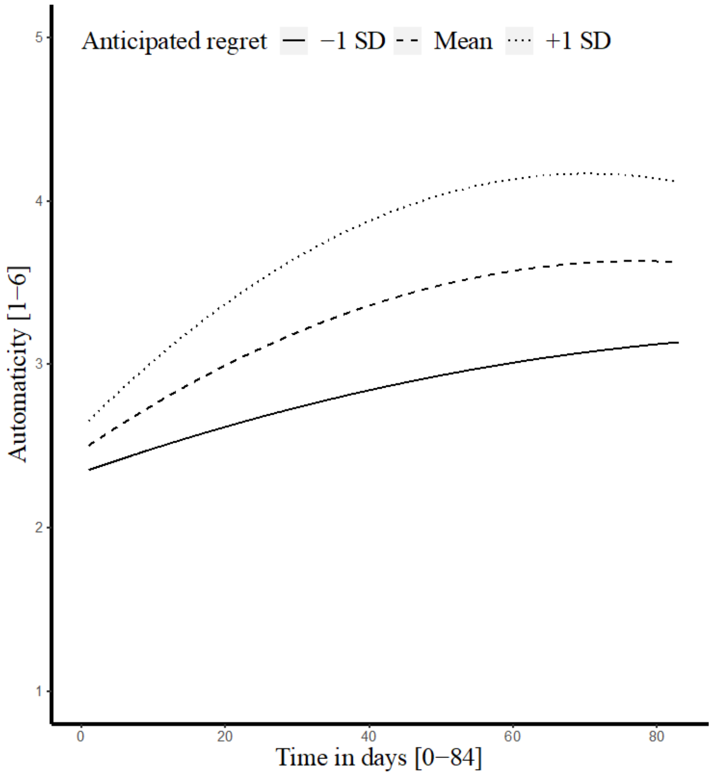
Automaticity Curves by Distinct Levels of Between-Person Intrinsic Reward Across 84 Days



Note. *n* = 135 participants. Curve for lower intrinsic reward (*M* – 1*SD*): The maximum automaticity of 2.91 was reached at the end of data collection (Day 84). Curve for mean intrinsic reward: The maximum automaticity of 3.64 was reached after 81 days. Curve for higher intrinsic reward (*M* + 1*SD*): The maximum automaticity of 4.40 was reached after 78 days.

Figure B.2

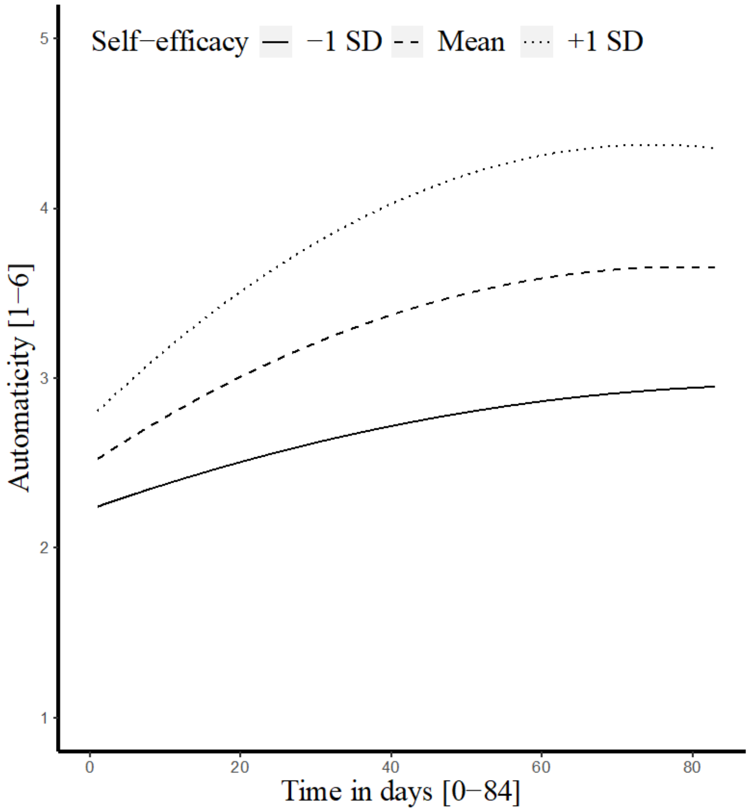
Automaticity Curves by Distinct Levels of Between-Person Anticipated Regret Across 84 Days



Note. *n* = 135 participants. Curve for lower anticipated regret (*M* – 1*SD*): The maximum automaticity of 3.14 was reached at the end of data collection (Day 84). Curve for mean anticipated regret: The maximum automaticity of 3.63 was reached after 78 days. Curve for higher anticipated regret (*M* + 1*SD*): The maximum automaticity of 4.17 was reached after 70 days.

Figure B.3

Automaticity Curves by Distinct Levels of Between-Person Self-Efficacy Across 84 Days



Note. n = 135 participants. Curve for lower self-efficacy (*M* – 1*SD*): The maximum automaticity of 2.95 was reached at the end of data collection (Day 84). Curve for mean self-efficacy: The maximum automaticity of 3.65 was reached after 79 days. Curve for higher self-efficacy (*M* + 1*SD*): The maximum automaticity of 4.37 was reached after 75 days.

Table B.1

Interaction Terms of Within- and Between-Person Intrinsic rewards, Anticipated regret, and Self-efficacy with a Linear and Quadratic Time Trend

Outcome Automaticity	***Predictor: Intrinsic reward***			***Predictor: Anticipated regret***			***Predictor: Self-efficacy***		
Fixed Effects									
	***B* (*SE*)**	***p***	***CL_{95}***	***B (SE)***	***p***	***CL_{95}***	***B* (*SE*)**	***p***	***CL_{95}***
Intercept	3.34 (0.07)	<.001	[3.21; 3.48]	3.30(0.08)	<.001	[3.15; 3.45]	3.32 (0.07)	<.001	[3.18; 3.47]
Linear time	0.00 (0.00)	<.001	[0.00; 0.01]	0.00 (0.00)	<.001	[0.00; 0.01]	0.00 (0.00)	<.001	[0.00; 0.01]
Quadratic time	-0.00 (0.00)	<.001	[-0.00; -0.00]	-0.00 (0.00)	<.001	[-0.00; -0.00]	-0.00 (0.00)	<.001	[-0.00; -0.00]
Within-person automaticity (previous-day)	0.61 (0.02)	<.001	[0.58; 0.65]	0.63 (0.02)	<.001	[0.60; 0.67]	0.63 (0.02)	<.001	[0.59; 0.66]
Within-person predictor variable (previous-day)	-0.01 (0.01)	.660	[-0.06; 0.02]	-0.00 (0.02)	.605	[-0.04; 0.02]	-0.00 (0.01)	.852	[-0.05; -0.00]
Within-person predictor variable (same-day)	0.15 (0.02)	<.001	[0.01; 0.02]	0.07 (0.01)	<.001	[0.03; 0.09]	0.06 (0.01)	<.001	[0.04; 0.10]
Between-person predictor variable	0.62 (0.08)	<.001	[0.46; 0.76]	0.27 (0.07)	<.001	[0.12; 0.41]	0.57 (0.11)	<.001	[0.37; 0.81]
Within-person predictor variable X linear time (same-day)	0.00 (0.00)	.079	[-0.00; -0.00]	-0.00 (0.00)	.295	[-0.00; 0.00]	-0.00 (0.00)	.304	[-0.00; 0.00]
Between-person predictor variable X linear time	0.00 (0.00)	.001	[0.00; 0.00]	0.00 (0.00)	.019	[0.00; 0.00]	-0.00 (0.00)	<.001	[0.00; 0.00]
Within-person predictor variable X quadratic time (same-day)	0.00 (0.00)	.508	[-0.00; 0.00]	-0.00 (0.00)	.532	[-0.00; 0.00]	-0.00 (0.00)	.714	[-0.00; 0.00]
Between-person predictor variable X quadratic time	0.00 (0.00)	.003	[-0.00; -0.00]	-0.00 (0.00)	.021	[-0.00; -0.00]	-0.00 (0.00)	<.001	[-0.00; -0.00]
Within-person plan enactment (previous-day)	-0.06 (0.01)	<.001	[-0.08; -0.04]	-0.06 (0.01)	<.001	[-0.08; -0.04]	-0.06 (0.01)	<.001	[-0.08; -0.04]

Within-person plan enactment (same-day)	0.20 (0.01)	<.001	[0.18; 0.22]	0.22 (0.01)	<.001	[0.19; 0.28]	0.20 (0.01)	<.001	[0.17; 0.25]
Between-person plan enactment	1.07 (0.24)	<.001	[0.59; 1.53]	1.59 (0.27)	<.001	[1.01; 2.07]	0.66 (0.35)	.059	[-0.07; 1.29]
Age	-0.01 (0.01)	.370	[-0.03; 0.01]	-0.00 (0.01)	.893	[-0.02; 0.02]	-0.01 (0.00)	.593	[-0.03; 0.01]
Sex	0.04 (0.03)	.179	[-0.02; 0.08]	0.05 (0.03)	.076	[-0.01; 0.09]	0.04 (0.03)	.124	[-0.01; 0.09]
Body-Mass-Index	-0.03 (0.02)	.117	[-0.06; 0.01]	-0.03 (0.02)	.127	[-0.06; 0.01]	-0.02 (0.02)	.212	[-0.06; 0.01]
Intervention condition	-0.03 (0.02)	.158	[-0.06; 0.01]	-0.02 (0.02)	.213	[-0.06; 0.01]	-0.01 (0.02)	.524	[-0.05; 0.02]
Random Effects ([co-]variances)									
Level 2 (between-person)	***Var* (*SE*)**	***p***	***CL_{95}***	***Var* (*SE*)**	***p***	***CL_{95}***	***Var* (*SE*)**	***p***	***CL_{95}***
Intercept	0.54 (0.07)	<.001	[0.42; 0.68]	0.70 (0.09)	<.001	[0.55; 0.89]	0.65 (0.08)	<.001	[0.51; 0.83]
Linear Time	0.00 (0.00)	<.001	[0.00; 0.00]	0.00 (0.00)	<.001	[0.00; 0.00]	0.00 (0.00)	<.001	[0.00; 0.01]
Within-person automaticity (previous-day)	0.03 (0.01)	<.001	[0.02; 0.05]	0.03 (0.00)	<.001	[0.02; 0.04]	0.02 (0.00)	<.001	[0.02; 0.04]
Within-person predictor (same-day)	0.03 (0.01)	<.001	[0.02; 0.05]	0.01 (0.00)	.010	[0.00; 0.01]	0.01 (0.01)	.001	[0.00; 0.01]
Intercept and within-person predictor (same-day)	0.06 (0.02)	<.001	[0.03; 0.10]	0.03 (0.01)	.007	[0.01; 0.06]	0.02 (0.01)	.030	[0.00; 0.04]
Within-person predictor (previous-day)	0.00 (0.00)	.143	[0.00; 0.00]	0.00 (0.00)	.060	[0.00; 0.01]	0.00 (0.00)	.063	[0.00; 0.01]
Intercept and within-person predictor (previous day)	-0.02 (0.01)	.025	[-0.05; -0.00]	0.00 (0.01)	.993	[-0.02; 0.02]	0.00 (0.00)	.754	[-0.01; 0.02]
Level 1 (within-person)									
Residual	0.11 (0.00)	<.001	[0.11; 0.12]	0.11 (0.00)	<.001	[0.11; 0.11]	0.11 (0.00)	<.001	[0.10; 0.11]

Autocorrelation	-0.23 (0.02)	<.001	[-0.27; -0.20]	-0.24 (0.02)	<.001	[-0.27; -0.20]	-0.24 (0.02)	<.001	[0.00; 0.01]

Note. *n* = 135 participants, 84 days, 11340 diary days. *SE* = standard error. Time trends were z-standardized and centred at day 42 (D42) of the study. Random effects structure was reduced to allow for convergence of the model

[a] degrees of freedom were specified based on the number of subjects (N=135)

Appendix C

Supplementary Material for Study 3

Note that Appendix C was not included in the online version.

Curriculum Vitae

Work experience

Since 12/2024	Psychotherapist, University outpatient department, Medical School Berlin
05/2021 – 10/2024	Research assistant, Division of Health Psychology, Freie Universität Berlin, External Funding Project: *„Developing a Taxonomy of Dyadic Behavior Change Techniques“*
01/2021 – 12/2023	Outpatient Psychotherapy, Psychotherapist in Training, Berlin
12/2020 – 03/2021	Research assistant, Department Gender in Medicine, Charité Universitätsmedizin Berlin
12/2019 – 11/2020	Friedrich von Bodelschwingh Hospital, Department of Psychiatry, Psychotherapy, and Psychosomatics, Trainee Psychotherapist, Clinical Practice I
02/2019 – 11/2019	Kokon - Center for Outpatient Drug Therapy, Trainee Psychotherapist, Clinical Practice II
10/2018 – 08/2019	Research assistant, Division of Health Psychology, Freie Universität Berlin
07/2017 – 07/2018	Student Assistant in the "PrevOP Study," Devision of Health Psychology, Freie Universität Berlin
12/2016 – 02/2018	Research Internship, Clinic and Outpatient Clinic for Psychiatry and Psychotherapy, Charité - Universitätsmedizin Berlin, Benjamin Franklin Campus
01/2015 – 01/2016	Staff, Division of Health Psychology, Freie Universität Berlin, External Funding Project: "Days in Motion" Study
09/2014 – 10/2014	Research Internship, Division of Health Psychology, Freie Universität Berlin, External Funding Project: "Days in Motion" Study

Teaching

2019 – 2024	Annual seminar "Social relationships and health" (Master of Psychology), Freie Universität Berlin
2020, 2023, 2024	Annual seminar "Stress and coping" (Master of Psychology), Freie Universität Berlin

Education

Since 04/2021	PhD Candidate in the Division of Health Psychology, Freie Universität Berlin under the supervision of Professor Dr. Nina Knoll
09/2018 – 09/2023	Psychotherapy Trainee at DGVT Berlin, specializing in Cognitive Behavioral Therapy
10/2015 – 09/2018	M. Sc. in Psychology from Humboldt Universität Berlin; Specialization: Clinical Psychology
03/2016 – 02/2017	Coaching Certification, German Association for Positive Psychology, Berlin
10/2011 – 09/2015	Bachelor of Science in Psychology, Technische Universität Dresden
09/2013 - 07/2014	Study Abroad (Erasmus), Libera Università Maria Ss. Assunta, Rome

Scholarships

10/2024	One-week Erasmus+, staff mobility for teaching
03/2016 – 09/2017	Germany Scholarship Recipient in the thematic class "Image Knowledge Design" at Humboldt Universität Berlin

List of Publications

Articles in Peer-Reviewed Journals (**+** indicates those articles that are part of this thesis)

+ Di Maio, S., Wilhelm, L. O., Fleig, L., Knoll, N., & Keller, J. (2025). Habit substitution toward more active commuting. *Applied Psychology: Health and Well-Being*, *17*(1), Article e12623, https://doi.org/10.1111/aphw.12623

Lorbeer, N., Schwarzer, R., Keller, J., **Di Maio, S.**, Domke, A., Armbrecht, G., Börst, H., Martus, P., Ertel, W., Luszczynska, A., & Knoll, N. (2024). Volitional processes in changing physical activity: A randomized controlled trial with individuals with knee osteoarthritis. *Health Psychology.* https://doi.org/10.1037/hea0001453

Di Maio, S.*, Villinger, K.*, Knoll, N., Scholz, U., Stadler, G., Gawrilow, C., & Berli, C. (2024). Compendium of dyadic intervention techniques (DITs) to change health behaviors: a systematic review. *Health Psychology Review*, *18*(3), 538-573. https://doi.org/10.1080/17437199.2024.2307534
*shared first authorship

Lorbeer, N.*****, Knoll, N.*, Keller, J., Domke, A., **Di Maio S.**, Armbrecht, G., Börst, H., Martus, P., Ertel, W., & Schwarzer, R. (2023). Enhancing physical activity and reducing symptoms of patients with osteoarthritis of the knee: a randomized controlled trial of the PrevOP-Psychological Adherence Program. *BMC Musculoskeletal Disorders, 24*, Article 550. https://doi.org/10.1186/s12891-023-06661-x
* Shared first authorship

+ Di Maio, S., Keller, J., Kwasnicka, D., Knoll, N., Sichert, L., Fleig, L. (2022). What helps to form a healthy nutrition habit? Daily associations of intrinsic reward, anticipated regret, and self-efficacy with automaticity, *Appetite, 175,* Article 106013. https://doi.org/10.1016/j.appet.2022.106083

+ Di Maio, S., Keller, J., Hohl, D. H., Schwarzer, R., & Knoll, N. (2021). Habits and self-efficacy moderate the effects of intentions and planning on physical activity. *British Journal of Health Psychology*, *26*(1), 50-66. https://doi.org/10.1111/bjhp.12452

Di Maio, S., Keller, J., Job, V., Felsenberg, D., Ertel, W., Schwarzer, R., & Knoll, N. (2020). Health demands moderate the link between willpower beliefs and physical activity in patients with knee osteoarthritis. *International Journal of Behavioral Medicine, 27*(4), 406-414. https://doi.org/10.1007/s12529-020-09865-w

Conference presentations (first authorships only)

Di Maio, S., Wilhelm, L. O., Fleig, L., Knoll, N., Keller, J. (2024, September 3-6). *Toward more active commuting habits* [Oral presentation]. 38th Annual Conference of the European Health Psychology Society, Cascais, Portugal.

Di Maio, S., Villinger, K., Knoll, N., Scholz, U., Stadler, G., Gawrilow, C., & Berli, C. (2024, July 5-9). *Compendium of dyadic intervention techniques (DITs)* [Oral presentation]. International Association for Relationship Research (IARR), Boston, MA, United States.

Di Maio, S., Wilhelm, L. O., Fleig, L., Knoll, N., Keller, J. (2023, September 4-8). *Substituting an old commuting habit with a more active and sustainable commuting habit* [Poster presentation]. 37th Annual Conference of the European Health Psychology Society, Bremen, Germany.

Di Maio, S., Villinger, K., Scholz, U., Knoll, N., Stadler, G., Gawrilow, C. & Berli, C. (2022, September 10-15). *Dyadic behavior change techniques in health behavior change interventions with romantic couples: A systematic review* [Oral presentation]. 51th Conference of the German Psychological Society (DGPs), Hildesheim, Germany.

Di Maio, S., Keller, J., Lorbeer, N., Kwasnicka, D., Wilhelm, L. O., Domke, A., Knoll, N. & Fleig, L. (2022, August 23-27). *Transmission effects in habit formation after planning to form two new Handwashing habits* [Oral presentation]. 36th Conference of the European Health Psychology Society, Bratislava, Slovakia.

Di Maio, S., Wermuth, K., Kühn, S., Dresler, M., Bublitz, J. C., & Repantis, D. (2022, June 07 - 10). *The role of compassion for the self and others in intrusion development following analogue trauma exposure* [Poster presentation]. German Psychotherapy Congress, Berlin, Germany.

Di Maio, S., Keller, J., Kwasnicka, D., Knoll, N., Sichert, L., Fleig, L. (2021, August 23-17). *Daily associations of intrinsic reward, anticipated regret, and self-efficacy with automaticity across 12 weeks* [Oral presentation]. 35th Annual Conferenceof the European Health Psychology Society, online conference.

Di Maio, S., Keller, J., Hohl, D. H., Schwarzer, R., & Knoll, N. (2021, June 30-July 2). *Habits and self efficacy moderate The effects of intentions and planning on physical activity* [Oral presentation]. Society for ambulatory assessment, online conference.

Di Maio, S., Keller, J., Job, V., Felsenberg, D., Ertel, W., Schwarzer, R., & Knoll, N. (2019, September 25-27). *Health Demands Moderate the Link Between Willpower Beliefs and Physical Activity in Patients with Knee Osteoarthritis.* 14*th* Kongress der Fachgruppe Gesundheitspsychologie, in Greifswald, Deutschland.

Di Maio, S., Roitzheim, C., Kappe, K., Hohl, D., Keller, J., Knoll, N., Burkert, S. (2015, September 17-20). *Wie Partner Einander bewegen. Partnerschaftliche Effekte auf die körperliche Aktivität* [Poster presentation]. 12th Kongress der Fachgruppe Gesundheitspsychologie, Graz, Austria. Poster award

List of Contributions

General Introduction and General Discussion

Sally Di Maio: writing - original draft preparation

Study 1

Sally Di Maio: conceptualization, methodology, formal analysis, writing – original draft preparation, visualization
Jan Keller: project administration, data curation, investigation, supervision, writing – review & editing
Hilda D. Hohl: project administration, data curation, investigation
Ralf Schwarzer: funding acquisition, supervision, writing – review & editing
Nina Knoll: funding acquisition, investigation, resources, supervision, writing – review & editing

Study 2

Sally Di Maio: conceptualization, methodology, formal analysis, writing original draft, visualization
Jan Keller: conceptualization, project administration, data curation, investigation, supervision, writing – review & editing
Dominika Kwasnicka: writing – original draft, writing – review & editing
Nina Knoll: methodology, resources, writing – review & editing
Lena Sichert: investigation, data curation, writing – review & editing, project administration
Lena Fleig: validation, investigation, writing – review & editing, project administration

Study 3:

Sally Di Maio: conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, writing – original draft preparation
Lea O. Wilhelm: validation, writing – review & editing
Lena Fleig: supervision, writing – review & editing
Nina Knoll: resources, validation, supervision, writing – review & editing
Jan Keller: funding acquisition, validation, resources, supervision, writing – review & editing

Eigenständigkeitserklärung

Hiermit erkläre ich, Sally Di Maio,

- dass ich die vorliegende Dissertation selbstständig verfasst und ohne unerlaubte Hilfe angefertigt habe.
- dass ich die Stellen der Arbeit, die dem Wortlaut oder dem Sinn nach anderen Werken (dazu zählen auch Internetquellen und KI-basierte Tools) entnommen sind, unter Angabe der Quelle kenntlich gemacht habe.
- Alle Hilfsmittel, die verwendet wurden, habe ich angegeben. Die Dissertation ist in keinem früheren Promotionsverfahren angenommen oder abgelehnt worden.

Berlin, 11.01.2025

Sally Di Maio